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THESIS

A SENSITIVITY ANALYSIS OF THE JANUS(A) COMBAT SIMULATION THAT SUPPORTS THE USE OF JANUS(A) IN ARMY TRAINING

by

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June, 1991

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that Supports the Use of Janus(A) in
Army Training

by

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I. INTRODUCTION

A. PURPOSE

This thesis concerns the potential benefits of linking the Janus(A) combat simulation with training conducted at the National Training Center (NTC). The primary objectives of this thesis are:

1. to identify potential training benefits gained by using Janus(A) to enhance post - NTC training;

2. to examine the sensitivity of the Janus(A) simulation to changes in a battle;

3. to develop a methodology for using Janus(A) to enhance a tactical commander's ability to determine training areas that require emphasis, and;

4. to apply work previously conducted by personnel at TRADOC Analysis Command-Monterey (TRAC-Monterey) in replicating NTC scenarios with Janus(A).

A secondary objective of this thesis is to provide information that may assist NTC personnel in accomplishing their mission.

B. SCOPE

The limited number of NTC laser (MILES instrumented) missions that have been successfully modified for execution as Janus(A) combat model scenarios constrained the scope of this thesis. There is one such scenario available at TRAC-Monterey. Currently, it requires approximately 300 hours to modify an NTC mission for execution in Janus(A) [Ref. 1:p. 40]. The available NTC battle is a Blue Force (BLUEFC~~)

battalion conducting a defense-in-sector mission against a Motorized Rifle Regiment (MRR). Some results of this thesis are limited to this battle and should not be applied to other NTC battles.

Chapter II of this thesis has a description of the Janus(A) combat model and the Army's National Training Center (NTC). The second chapter is not a detailed description of Janus(A) or the NTC; rather it contains a discussion of the basic components of each. Chapter III is a discussion of the process used to examine the sensitivity of the Janus(A) simulation. Only changes in the Blue Force's (BLUEFOR) operations are considered. The results of this examination are in Chapter IV. Chapter V provides the conclusions of this thesis and recommendations for future efforts related to Janus(A) and the NTC. The Appendix contains a discussion of how Janus(A) might be used by tactical units after they have trained at the NTC. It includes a method for using Janus(A) to enhance the tactical commander's ability to select areas that need future training emphasis.

II BACKGROUND

A. DESCRIPTION OF THE JANUS(A) COMBAT MODEL

1. General

The Janus(A) combat model is a high resolution computer simulation allowing both interactive and systemic operations. Interactive operation of Janus(A) allows operator interaction and simulates battles in near real time. Systemic processing is the ability to execute the Janus(A) model without operator interaction. This systemic mode can reduce run times to almost 50% of real (or interactive) times. [Ref. 1:p. 41]

The model is primarily a two-sided ground force model. Janus(A) can simulate both direct fire and indirect fire events [Ref. 2:p. 6]. Both direct and indirect fires were simulated during the battle considered in this thesis. Janus(A) can also simulate rotary and fixed-wing aircraft. The scenario considered in this thesis does not include simulation of aircraft.

2. Simulation of Terrain and Environment

Janus(A) simulates terrain using a system of cells arranged to represent a square section of terrain. The terrain is modeled as a square measuring 400 cells by 400

cells [Ref. 2:pp.35-37]. This is a total of 160,000 cells. Characteristics of the terrain such as foliage and elevation are constant within each cell.

For example, if the simulated area measures 40 kilometers by 40 kilometers then each cell represents a square measuring 100 meters by 100 meters. The Janus(A) terrain file number 850 represents the NTC maneuver area measuring 40 kilometers by 40 kilometers [Ref. 1]. This is the terrain file used throughout this thesis.

The Janus(A) data base contains up to 16 sets of weather conditions. Each set specifies conditions for visibility, humidity, temperature and sensor contrast. The condition set used in this thesis represents a desert environment with good (17 km) visibility, a temperature of 40°F and low humidity. [Ref. 1:p. 25].

3. Simulation of Combat Systems

Janus(A) can simulate 250 individual units for each opposing side. This force level is sufficient to represent a Motorized Rifle Regiment (MRR) and an Army Brigade consisting of three maneuver battalions. An individual unit can represent any one man, single vehicle, artillery piece, or similar entity. A unit can also represent a grouping of weapons, e.g., a four-tank platoon. All units of the same type have the same characteristics such as weapon type, sensor type, movement speeds, etc. The Janus(A) user sets these

characteristics. Janus(A) does not permit variations in characteristics such as crew proficiency between tanks, for example.

4. Simulation of Direct Fire Events

One-on-one stochastic attrition processes determine the rate at which units are attrited [Ref. 2:p. 6]. Comparison of random numbers to a user defined probability curve resolves each engagement. The Janus(A) probability-of-kill and probability-of-hit curves are functions of range to target, weapon system, target type, and target posture (in terms of movement and firing angle). This method of engagement resolution constitutes an overall Monte-Carlo approach. Units with the same weapon type have the same probability-of-hit and probability-of-kill functions. Figure 1 shows a hypothetical probability-of-kill curve for a stationary tank main gun weapon firing at a moving flank target. The Janus(A) user sets the ranges and corresponding probabilities based on the best classified or unclassified empirical data available.

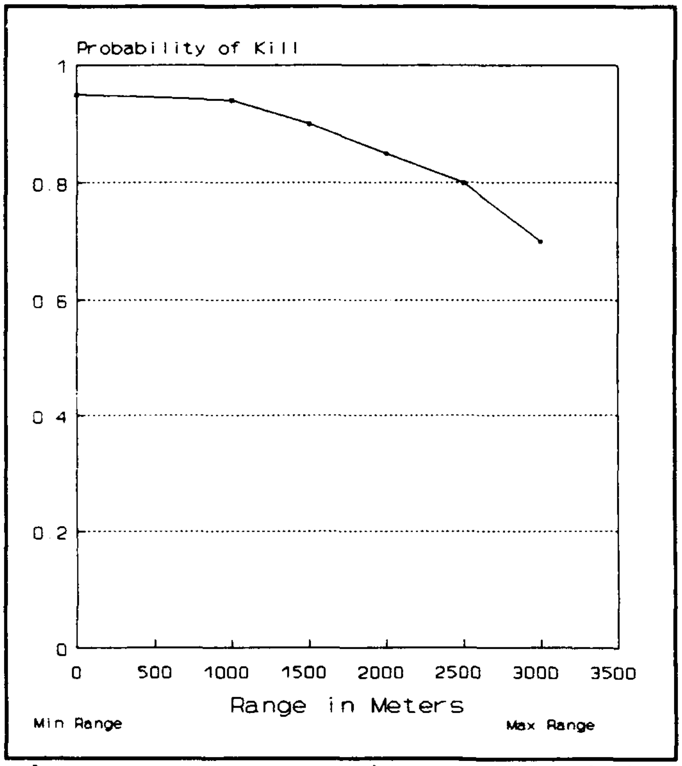

Figure 1 Hypothetical Probability of Kill Curve

5. Post Processing Data

a. Standard Post-Processing Files

Janus(A) can generate data files for post simulation analysis [Ref. 2:pp. G1-G14]. The files contain information such as number of artillery missions fired, attrition results, and engagement ranges. Janus(A) constructs similar files for each side. These files have a standard format, but are not readily imported into the statistical software package (STATGRAPHICS) used in this thesis. This import limitation is due to the repetition of header

information throughout the file. Janus(A) output files were useful for obtaining a first look at the results of simulated battles, but they were not used to provide the data analyzed in this thesis.

b. Specialized Post-Processing Files

Janus(A) can generate data files for use in the Lawrence Livermore National Laboratory Analyst Workstation (LLNL AWS) [Ref.1:p. 2]. This analyst workstation provides graphical representation of post-run data. Additionally, the files created as input for the LLNL AWS are in ASCII format, allowing import into the statistical software used in this thesis. TRAC-Monterey has also developed a FORTRAN program to collect data relating to attrition in the Janus(A) runs. The analyses in this thesis are based on these specialized post-processing files. Additional FORTRAN programs were written to further process information from these files. These programs and files are discussed in Chapter III.

B. DESCRIPTION OF THE NATIONAL TRAINING CENTER (NTC)

1. Mission

The Army established the National Training Center (NTC) at Fort Irwin, California, in 1981 to:

> (1) provide tough realistic combined arms and service joint training in accordance with Airland Battle doctrine for brigades and regiments in a mid to high intensity environment, while retaining the training feedback and analysis focus at Battalion and Task Force level; and,

(2) provide a data source for training, doctrine, organization, and equipment improvements. [Ref. 3:p. C1]

The results of this thesis should assist the NTC in achieving its mission by improving a training unit's use of NTC results.

2. Terrain

The Fort Irwin area is characterized by high desert terrain with approximately 430,000 acres for tracked vehicle movement and 640,000 acres overall. The varied terrain allows maneuver across desert valleys, mountains, and defiles. The relatively large area allows maneuver that is normally not available at a unit's home station.

3. Typical Training

A battalion-size unit deploys to the NTC for 20 days. During this period the unit conducts simulated force-on-force battles against an NTC-based Opposing Force (OPFOR). The OPFOR consists of two US battalions (one armor, one mechanized infantry) configured to replicate the signature of a motorized rifle regiment (MRR) [Ref. 3:p. C6]. The OPFOR uses visually modified US Army equipment to portray soviet weapon systems.

Each battalion conducts five to seven of these force-on-force battle simulations. The battalion trains under night and day conditions. NTC personnel conduct informal After Action Reviews (AARs) at the company and battalion levels after each force-on-force battle. The example training program suggested in the Appendix is linked to information unit personnel receive during these AARs.

4. Battle Monitoring System

The NTC maneuver area has an extensive system to monitor and record vehicle movement, direct fire engagements and command and control operations [Ref. 3:p. C13]. The data acquired by this system are collected. The collected data provide the basis for the After Action Reviews (AARs), Take Home Packages (THPs), and video replays of AARs. Units receive copies of the AARs, THPs and video replays. The battle monitoring system has limitations in recording all unit movement and events. These limitations are one reason it takes approximately 300 man-hours to replicate an NTC battle in Janus(A) [Ref. 1:p. 53].

5. Simulation of Direct Fire Events

Direct Fire events during force-on-force (laser) simulations are resolved using the Multiple Integrated Laser Effects System (MILES) [Ref. 3:p. C10]. There are approximately 550 MILES equipment sets at the NTC [Ref. 3:p. C10]. The MILES uses an eye-safe laser to simulate the firing of a direct fire weapon. Each laser emission is coded to represent the firing weapon. If struck by a MILES's beam, the MILES equipment on the target vehicle uses the coded information to determine if it has been killed. If the target system has been killed, that fact is transmitted to the battlefield monitoring system. The battlefield monitoring system records killer type, target location, and killer

location when a firing element successfully engages another element. After a successful kill, MILES prohibits the target system from engaging other elements.

6. Post-NTC Training Material

The Take Home Package (THP) normally includes AAR information organized on the basis of the seven Battlefield Operating Systems (BOS) [Ref. 3:p. D1]. The NTC provides THPs for company and battalion levels. The THPs include information on,

1. the attrition of OPFOR attributed to each BLUEFOR company;
2. the ammunition expenditure by weapon system;
3. the rounds per kill for each direct fire weapon;
4. the total attrition of each side; and,
5. a record of graphical control measures (video).

The packet does not recommend a methodology to improve on training related performance deficiencies demonstrated by the unit at the NTC. The example methodology discussed in the Appendix is designed to aid units in identifying such deficiencies and in selecting corrective actions.

C. TECHNICAL REPORT: COMPARISON OF THE JANUS(A) COMBAT MODEL TO NATIONAL TRAINING CENTER (NTC) BATTLE DATA

1. Purpose and Scope

As part of an ongoing Army Regulation 5-5 Study called Janus and NTC Comparison, TRAC-Monterey has completed a draft

technical report, Comparison of The Janus(A) Combat Model to National Training Center (NTC) Battle Data / TRAC-RDM-TR-191 [Ref 1]. The draft report published in March 1991 documented phase II of the Janus and NTC comparison and had three objectives:

1. to enhance documentation of the process (process also referred to as qualification) used to modify an archived NTC battle for execution in the Janus(A) combat simulation;

2. to conduct data comparison between the actual NTC battle and the replicated Janus(A) scenario; and,

3. to identify limitations discovered in the qualification process [Ref. 1:p. 1].

The report included information on the qualification of a single defense-in-sector battle. This thesis is an extension of these efforts by TRAC. Much of the research and all the actual simulation were conducted at the TRAC-Monterey facility. The results in this thesis may help TRAC's future efforts in phase III of the Janus and NTC Comparison Study.

2. Results and Recommendations

a. Results

The technical report documented the qualification procedure applied to an NTC battle. It identified the steps necessary to adapt NTC digital data for use in Janus(A). Direct fire intensity and attrition were used to compare the Janus(A) battle with the original NTC battle. The report concluded that overall BLUEFOR volume of fire was slightly lower in Janus(A) than at the NTC. The report also concluded

that a comparison of temporal and spatial direct fire data indicated differences in most BLUEFOR companies. Those companies or crews identified at the NTC as having poor command and control or below average crew performance had a statistically significant lower volume-of-fire than corresponding replicates in Janus(A). [Ref. 1:pp. 41-47]

Attrition summary, and temporal-spatial data indicated that the BLUEFOR and OPFOR abilities to kill are significantly greater in Janus(A) than at the NTC. The report attributed much of this difference to the greater single-shot-kill probabilities (SSKPs) used in Janus(A) during this simulation. Because the Janus(A) probability-of-kill for each weapon were modified to reflect NTC MILES relationships, the report judged probability-of-hit to be the basis for SSKP differences. This is reasonable because Janus(A) uses SSKP = probability-of-hit x probability-of-kill (SSKP = PH x PK). The report concluded that the proba.ility of hit data used within Janus(A) are optimistic as compared to those demonstrated in this NTC battle [Ref. 1:pp. 47-52].

<u>b. Recommendations</u>

The technical report states four recommendations. First, that tactical commanders use this ability to replicate NTC battles within Janus(A) to enhance their training after an NTC rotation. This thesis is one result of this recommendation. Second, that the NTC data collection process

should be changed to increase the accuracy of collected data and to reduce the time required to qualify NTC missions in Janus(A). Third, that the qualification process should be automated to the greatest possible extent. The report states that automation will reduce the estimated 300 man-hour qualification process. Fourth, that improvements should be made in Janus(A) so that algorithms portray more accurately variations in company or crew performance. [Ref. 1:pp. 53-60]

D. US GENERAL ACCOUNTING OFFICE REPORT, NTC POTENTIAL

In the summer of 1986 the General Accounting Office (GAO) completed a report to the Secretary of the Army entitled ARMY TRAINING National Training Center's Training Potential Has Not Been Realized [Ref. 4]. The GAO sought to determine if the Army was using the information collected from NTC exercises to analyze deficiencies in unit performance, to determine their causes and initiate solutions. The study concluded that the Army had not used the objective data for overall assessment of organizations or weapon systems. The GAO determined that the Army had not identified causes of Army-wide deficiencies nor had the Army initiated solutions. The study recommended that the Army address the development of performance measures, task lists and analysis methodologies. The study identified integrating home station training with NTC training as an Army-identified objective that would help to solve the data analysis problem. This thesis provides an example of how a

unit might integrate post-NTC training and Janus(A). [Ref. 4:pp. 2-4]

III PROCESS FOR EVALUATING THE SENSITIVITY OF JANUS(A)

A. GENERAL

The objective of the five-part proccss for evaluating the sensitivity of Janus(A) is to investigate how sensitive the Janus(A) output is to changes in the BLUEFOR operation. Figure 2 depicts this five part process.

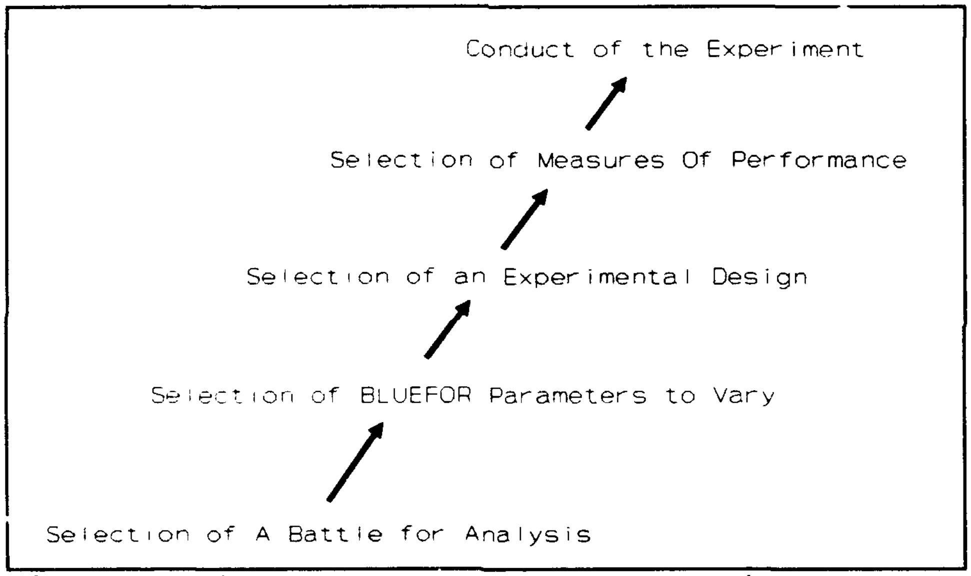

Figure 2 Five Part Process for Evaluating Janus(A) Sensitivity

This process required the selection of at least one Measure of Performance (a response variable sensitive to changes in BLUEFOR operations). This Measure Of Performance

(MOP) provides information on how the simulation reacts to BLUEFOR changes. Since the selected response variable indicates how well the BLUEFOR accomplished its mission, it is a measure of the BLUEFOR's performance. Because of this relationship to the BLUEFOR operation, the response variable was referred to as a Measure Of Performance (MOP). The MOP is described in detail in section III E.

Selected areas of the BLUEFOR operation are modified by changing certain battle parameters. The parameters are equivalent to the main effects (factors) of an experimental design. A discussion of the parameters used in this thesis is given in section III C. The process involves exploring the relationships between the parameters (main effects) and the MOP (response variable) with the 2^K factorial design described in section III D.

B. PART I. SELECTION OF A BATTLE FOR ANALYSIS

1. General

The selected battle was the NTC Defense in Sector (DIS) battle discussed in the TRAC-Monterey Technical Report [Ref. 1]. There are two reasons for selecting this battle. First, the fact that this mission was previously simulated at the NTC lends credibility to this DIS scenario. The development of a similar, but original Janus(A) scenario would require the justification of force disposition, enemy course of action, etc. Selecting this DIS battle removes the need

for such justification. Second, the qualification of another NTC battle would currently require an additional 300 man-hours, which would significantly delay the project's completion.

2. Description of the Selected Battle

a. Duration and Critical Events

The actual NTC battle occurred in fiscal 1988 from approximately 12:00 p.m. until 4:40 a.m. This period includes the start of the DIS mission until the time when the BLUEFOR received an order to change its mission. The total battle time was approximately 300 minutes [Ref. 1:p. 14].

The TRAC-Monterey technical report selected a 160 minute segment of the NTC battle for simulation in Janus(A) [Ref. 1:p. 14]. The period covered is 2:00 a.m. through 4:40 a.m. Three factors determined this 160 minute time segment. First, the Janus(A) simulation available at TRAC-Monterey currently limits a single NTC simulation to approximately 245 minutes. This prohibits simulation of the complete NTC battle in Janus(A). Second, the most critical events occurred during this 160 minute period. Table I lists critical NTC battle events [Ref. 1:p. 13].

Table I CRITICAL EVENTS, NTC BATTLE

TIME - 24 Hour clock	Event
0200	OPFOR Forward Detachment(Fwd Det) crosses Phase Line (PL) Wendy
0225	OPFOR Fwd Det vicinity TRP 11. Lead Elements of MRR vicinity 37 grid line
0245	MRR vicinity PL Whitley Team (Tm) F engages Fwd Det from BP 21A
0300	MRR vicinity 48 98 grid square. Tm F and D Company (Co) engage Fwd Det in Engagement Area (EA) Cuda.
0330	D company lost 5 of 10 tanks, and one Improved TOW Vehicle (ITV). Fwd Det is combat ineffective. MRR vicinity Target Reference Point (TRP) 11.
0400	Lead elements of MRR vicinity EA Piranha. D Co(-), Tm F and B Co are combat ineffective.
0430	MRR crosses PL Abercrombie with approximately 60% strength.
0440	BLUEFOR receives change of mission

The third factor supporting selection of this time segment was the NTC digital data. The data base was available for the period 2:00 a.m. to 4:40 a.m. [Ref. 1:p. 14].

b. Disposition of Forces

Table II lists the critical direct fire systems present at the beginning of the battle [Ref 5].

Table II CRITICAL DIRECT FIRE SYSTEMS

Critical BLUEFOR Direct Fire Systems						
SYSTEM	UNITS					
	Team A	Team B	Team F	Team D	Task Force Control	Total
Tank	10	13	4	10	2	39
M2/M3 Bradley	7	0	7	0	4	18
ITV	0	0	0	5	0	5
APC	3	2	5	3	5	18
Critical OPFOR Direct Fire Systems						
SYSTEM	UNITS					
	Fwd Det	1st Echelon	2nd Echelon	Regimental Control		Total
Tank	13	26	16	1		56
BMP	21	46	32	9		108
BRDM	1	1	0	5		7
MTLB	16	0	0	0		16

Figures 3 through 8 indicate the disposition of both OPFOR and BLUEFOR elements at the beginning of the Janus(A) simulation. Figure 3 depicts the overall BLUEFOR.

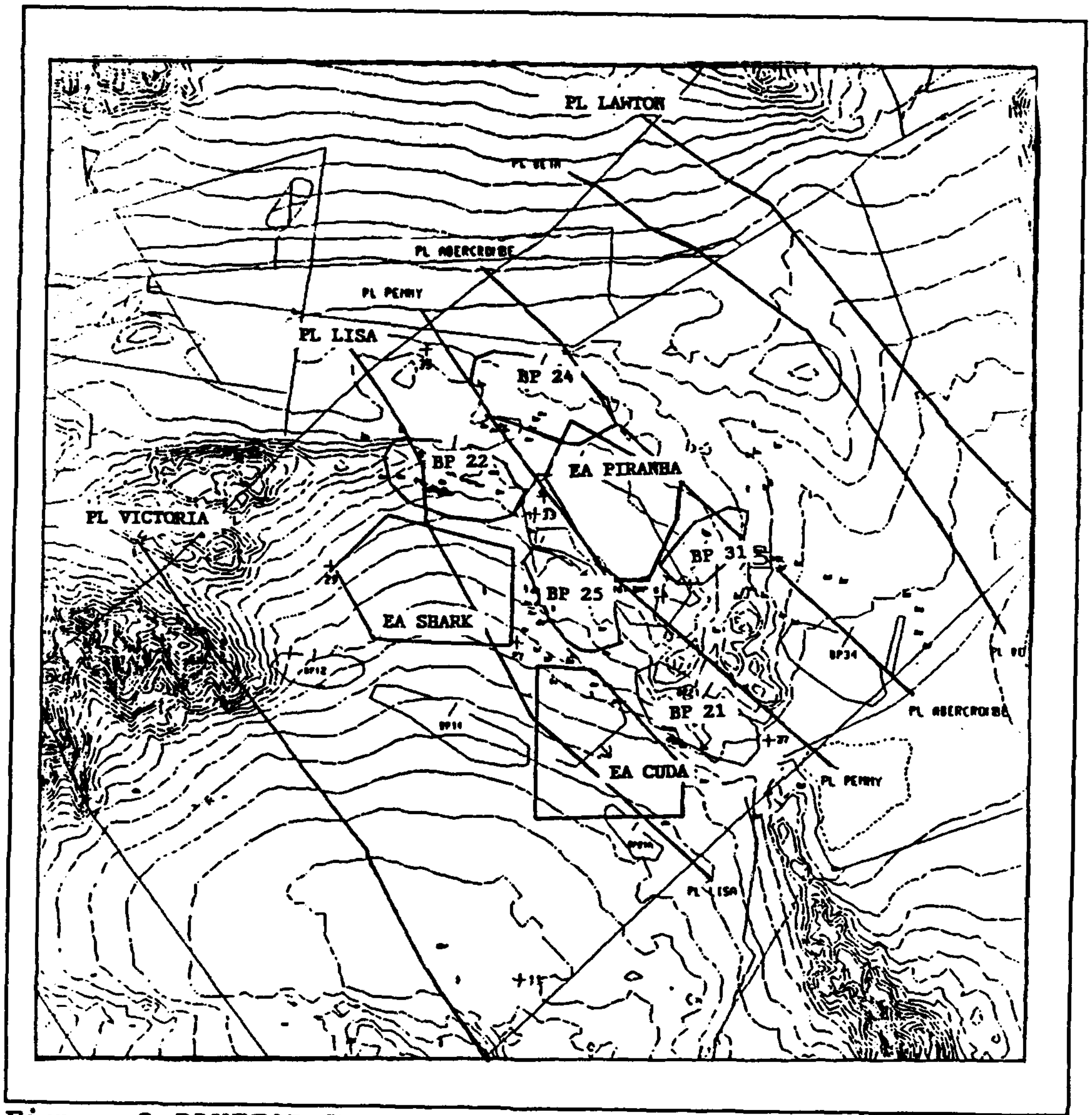

Figure 3 BLUEFOR Forces and Operational Graphics

Figure three shows graphics that the BLUEFOR commander used to orient his forces to the South-West along the anticipated enemy avenue of approach. Also shown are the vehicle positions of the BLUEFOR Companies and Teams. The BLUEFOR reconnaissance element (Team Scout) was located along Phase Line (PL) Victoria.

Figures three, four, five, and six show individual company positions. These figures are from the qualified Janus(A) battle. The Janus(A) simulation uses numerical designations for companies and teams. In this scenario Team A elements are designated by "2", Team B by "4", D Co(-) by "5", and Team F by "3". Team A occupied Battle Position (BP) BP 22 at the start of the battle. Team A was to orient fires into engagement area (EA) Shark.

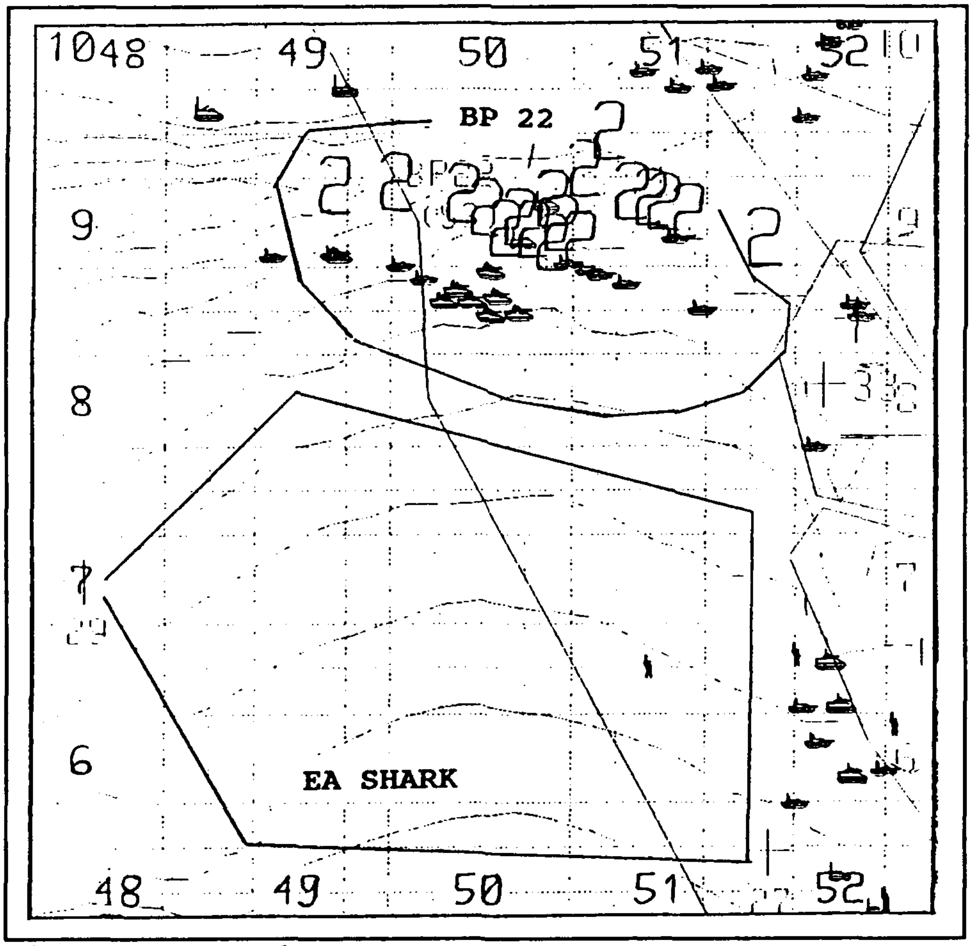

Figure 4 Location of BLUEFOR Team A

Team B occupied in the area of BP 24. Their mission was to destroy forces in EA Piranha and on order act as the BLUEFOR reserve.

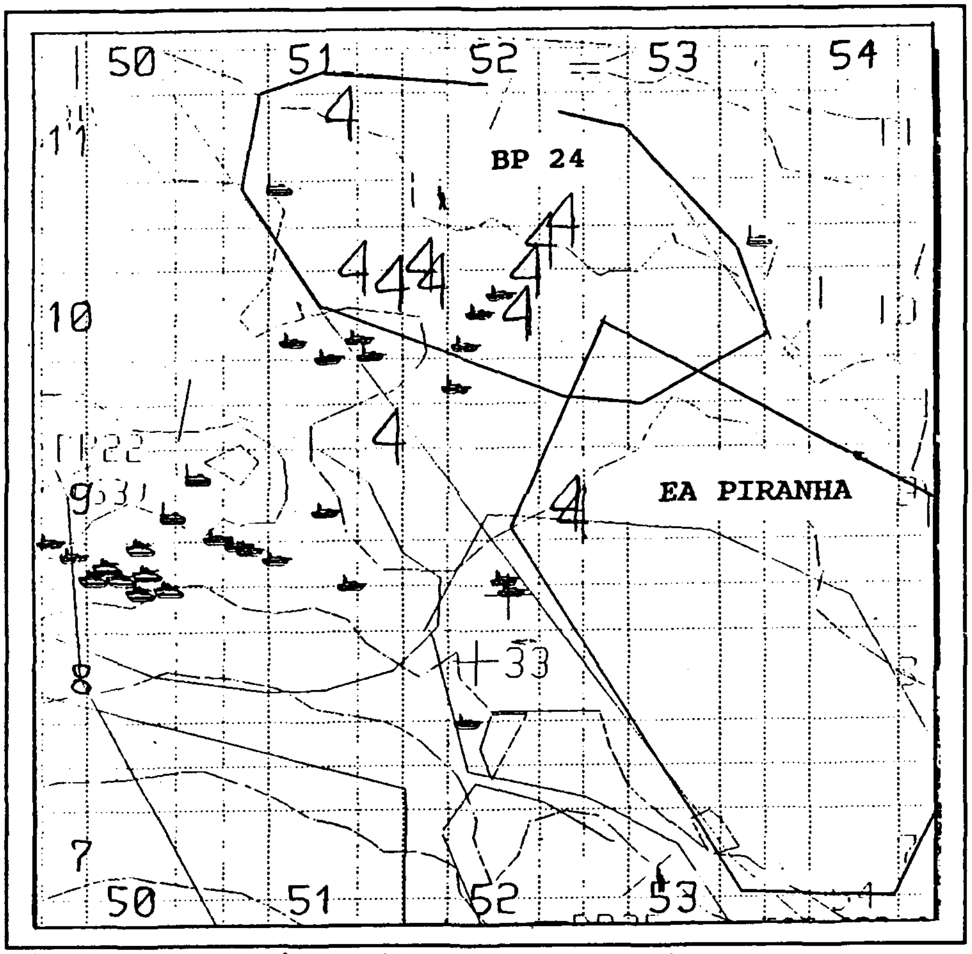

Figure 5 Location of BLUEFOR Team B

D Company minus (D Co (-)) established positions forward of BP 25. The forward positions were an attempt to deceive the OPFOR. The deception was designed to persuade the OPFOR into believing the BLUEFOR was farther to the West than its actual Battle Positions.

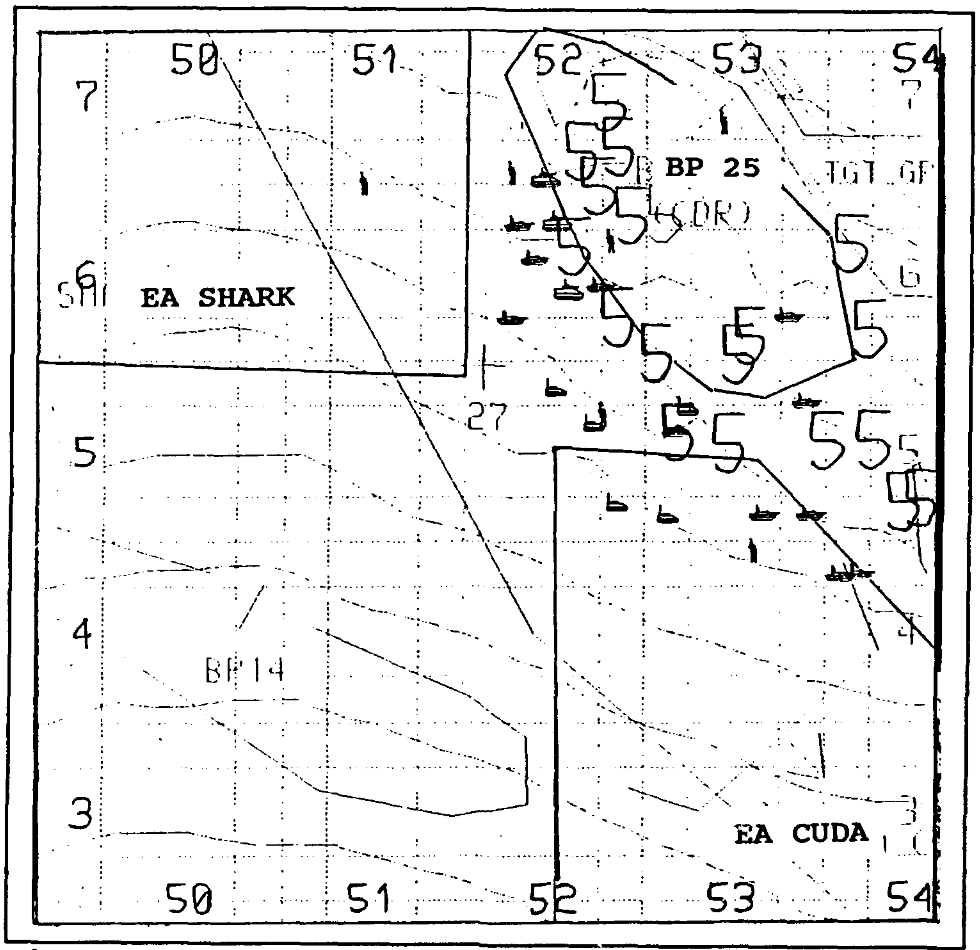

Figure 6 Location of BLUEFOR D Co(-)

Team F was located West of Battle Position 21; near an area referred to as Red Pass. Team F was to orient its fires into EA Cuda and on order react to the North to destroy OPFOR elements in EA Piranha.

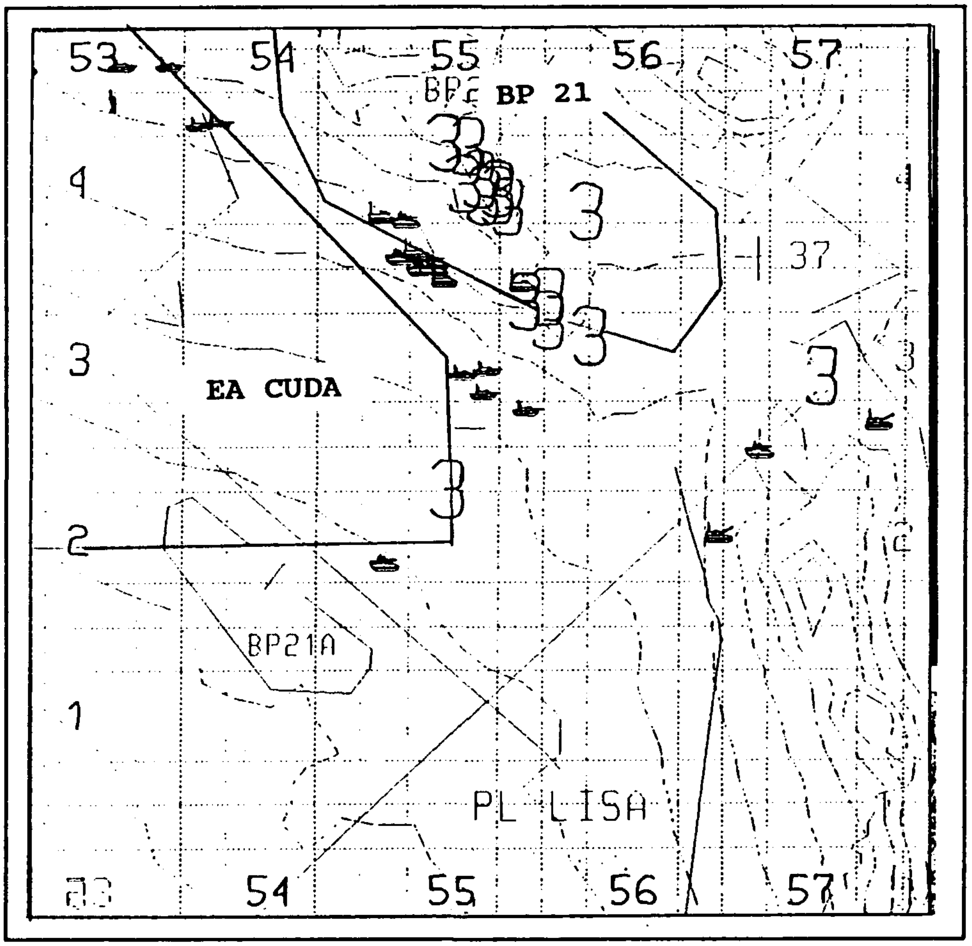

Figure 7 Location of BLUEFOR Team F

The OPFOR positioned themselves to the West of the initial BLUEFOR positions. Figure eight depicts the OPFOR at the start of the Janus(A) simulation. At the beginning of the 160.0 minute segment some OPFOR reconnaissance elements had penetrated the BLUEFOR sector.

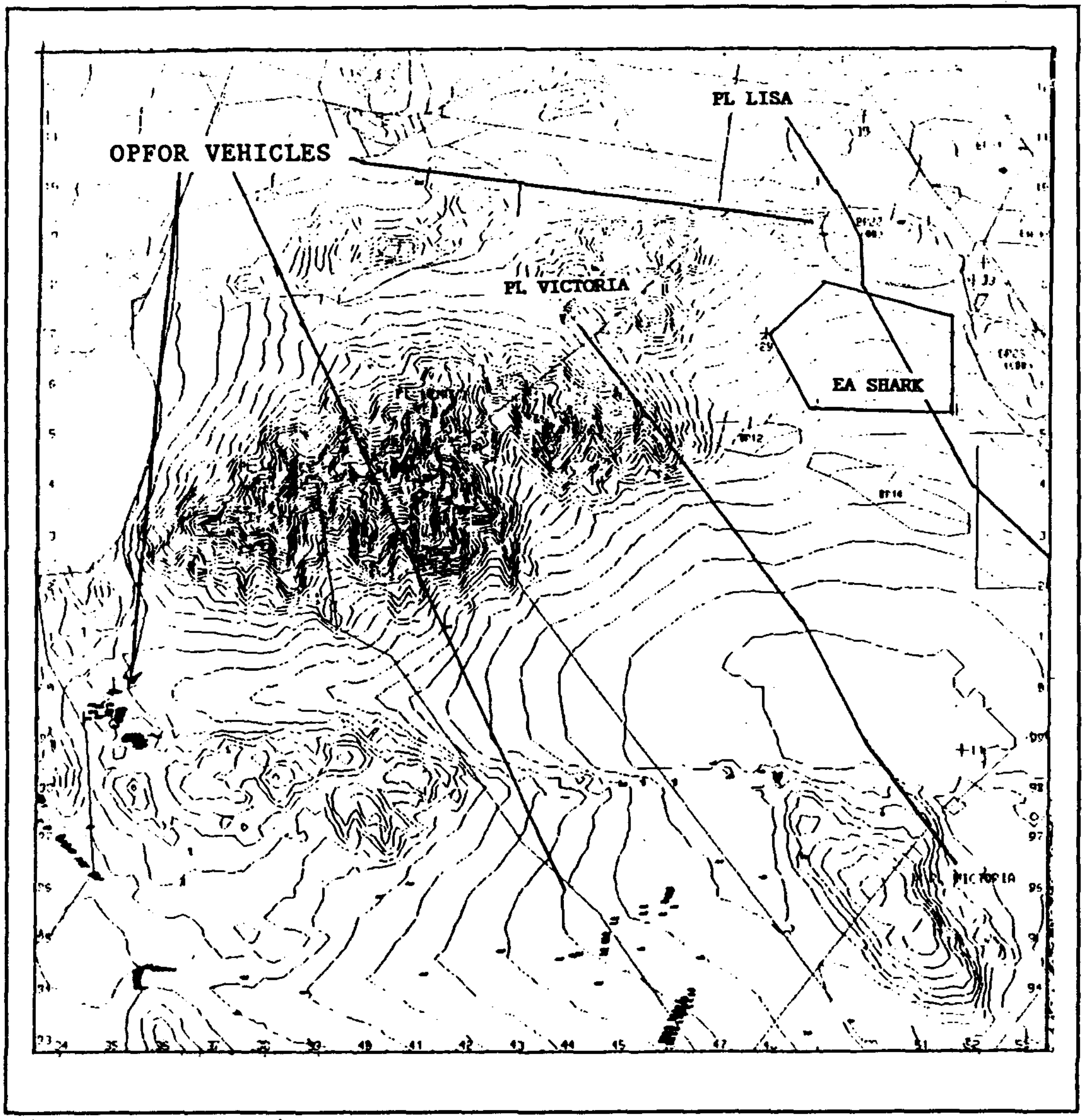

Figure 8 Location of OPFOR Elements

c. Blue Force: Defender

(1) Mission The THP contains the BLUEFOR commander's mission statement. The mission statement read in part,"Task Force...defends in sector from PL VICTORIA to PL GERALD [Northweast of PL Lawton] NLT 242400 [-------] 88 to destroy enemy forces and allow no penetration of PL LAWTON." [Ref. 5]

(2) BLUEFOR Concept of the Operation Additional guidance on how the commander wanted to accomplish the BLUEFOR mission is included in the commander's concept of the operation. The concept had two phases. The first phase was an aggressive counter-reconnaissance battle. This counter-reconnaissance battle required destruction of the OPFOR's reconnaissance assets to include the Forward Detachment and Deep Reconnaissance Teams (DRTs). The second phase of the BLUEFOR operation was to destroy the remaining OPFOR elements in Engagement Areas (EAs) Shark, Piranha and Cuda. [Ref. 5]

(3) BLUEFOR Task Organization Table III shows the BLUEFOR task organization. The Janus(A) simulation included three artillery batteries not listed in this task organization. These batteries fired missions in support of the BLUEFOR and its parent Brigade at the NTC. These missions are conducted in the Janus(A) scenario as well. The parameter changes used in this thesis did not involve the BLUEFOR artillery.

Table III BLUEFOR TASK ORGANIZATION

Tm Scout	Tm A	Tm F
Scout Platoon	1 PLT / A Armor	1 PLT / A Mech
2 x Stinger Sect.	2 PLT / A Armor	3 PLT / A Mech
	2 PLT / A Mech	3 PLT / A Armor
	2 PLT / B Mech	1 Stinger Sect.
B Co	D Co (-)	Task Force Control
1 PLT / B Armor	2 PLT / D Armor	HQ Tank Section
2 PLT / B Armor	3 PLT / D Armor	A / EN (-)
3 PLT / B Armor	1 PLT / E Anti-Tank	1 PLT / A / EN
1 Stinger Section	Vulcan PLT (DS)	Hvy Mortar PLT

d. Opposing Force: Attacker

(1) OPFOR Mission and Concept of the Operation The video portion of the THP included comments by the OPFOR commander. The OPFOR commander stated the following mission, "To conduct a Regimental attack from positions in contact at 250230[-------]88" [Ref. 5]. The purpose of this attack was to penetrate the BLUEFOR forward positions and destroy the majority of the BLUEFOR's combat power. The OPFOR was also to preserve enough of its own combat power to repel a BLUEFOR counter attack. The OPFOR commander inserted Deep Reconnaissance Teams (DRTs) and Regimental Reconnaissance Teams (RRTs) to collect intelligence on BLUEFOR activities.

The OPFOR commander then used this intelligence to develop his scheme of maneuver. [Ref. 5]

(2) OPFOR Task Organization Table IV lists the OPFOR combat units. Not shown are the OPFOR combat support (CS) and combat service support (CSS) units.

Table IV OPFOR TASK ORGANIZATION

Fwd Det	1st Ech**	2nd Ech	Regimental Control
2d MRB*	3d MRB	1st MRB	HQ Elements

* Motorized Rifle Battalion (MRB)
** Echelon (Ech)

e. NTC Battle Results

Two of the quantitative measures NTC personnel use to determine the results of a battle are force attrition and the average number of BLUEFOR rounds fired for each OPFOR kill (rounds-per-kill). The NTC personnel tabulate attrition results for both the OPFOR and BLUEFOR. The AARs include the rounds-per-kill information for BLUEFOR only.

The attrition information is used to determine how many of the OPFOR losses are attributed to BLUEFOR systems. This value is then used to assess how well the BLUEFOR performed the mission of destroying the OPFOR. Table V shows the attrition results for selected direct fire weapon systems.

The NTC personnel recorded a total 61 OPFOR vehicles and 47 BLUEFOR vehicles destroyed during the battle [Ref. 5].

Table V SELECTED NTC VEHICLE LOSSES

NTC Battle Losses for Critical Systems			
BLUEFOR		OPFOR	
System	Quantity Lost	System	Quantity Lost
Tank	29	Tank	18
M2/M3 Bradley	5	BMP	33
ITV	4	BRDM	5
APC	5	MTLB	2
TOTAL	43	TOTAL	58

The rounds-per-kill data are used to assess how efficient the BLUEFOR was at destroying OPFOR vehicles. Table VI shows the rounds-per-kill results of this NTC battle. For comparison, NTC personnel stated that the average rounds-per-kill for BLUEFOR tanks (11.7) was greater than the overall average for tanks at the NTC [Ref. 5].

Table VI ROUNDS EXPENDED AT THE NTC

BLUEFOR: Rounds Expended for Selected Systems at the NTC			
BLUEFOR Unit	Tank Main Gun	TOW Missile	M2/M3 Main Gun
Tm A	26	0	625
B Co	48	N/A	N/A
Tm F	81	2	900
D Co (-)	115	49	N/A
TOTAL Fired /OPFOR kills	304 / 26	51 / 2	1525 / 6

C. PART II. SELECTION OF THE BLUEFOR PARAMETERS TO BE VARIED IN JANUS(A)

1. General

Four battle parameters were selected:

1. the position of certain vehicles (vehicle positions);

2. the engineer survivability preparation of vehicle fighting positions (survivability positions);

3. the volume of fire for direct fire weapon systems (volume-of-fire), and;

4. the coordination of reserve force movement (coordination of reserve).

There are three reasons for selecting these parameters. First, comments in the THP indicated certain deficiencies in these factors during the actual NTC battle. The engineer failed to emplace all the survivability positions required by the BLUEFOR operations order (OPORD). The

majority of these survivability positions were to be located in the three Battle Positions (BPs) numbered BP 22, BP 25 and BP 21. According to the THP, the reserve force may have moved too late to significantly influence the battle, and the actual move was unorganized. The THP video AAR record of rounds fired showed that 24 vehicles did not fire during the battle. The personnel who conducted the AAR attributed this lack of fire to poor vehicle positioning and poor crew gunnery skills. [Ref. 5]

Second, changes in a selected parameter should not require changes in the OPFOR scheme of maneuver. The intent is to simulate the battle with changes in the BLUEFOR while the OPFOR's actions remain the same. This requires that the changes in the BLUEFOR operation be hard to detect by the OPFOR. Radical changes in the disposition of the BLUEFOR might very well provide additional information to OPFOR Deep Reconnaissance Teams and Regimental Reconnaissance Teams. This information would be in addition to that already gathered by the teams. With additional information the OPFOR commander could decide to change his scheme of maneuver.

Third, these four parameters have an assumed relationship to how well the BLUEFOR accomplished its mission. The mission entails destruction of the enemy and an inherent need to preserve the friendly forces. Survivability positions help to preserve the BLUEFOR. Changes in volume-of-fire, coordination of the reserve and vehicle positions support the

destruction of the OPFOR, as well as attempt to preserve the BLUEFOR.

Only one change is applied to each parameter. This equates to each parameter having two conditions or levels. One condition is the original state of the parameter in the qualified NTC scenario. The other condition or level is the result of a change to the BLUEFOR operation. For example, the number of survivability positions in the qualified scenario corresponds to one level of the survivability position parameter. Altering the number of survivability positions generates the second level of the survivability position parameter.

2. Vehicle Position Parameter

The change to vehicle positions was to move selected vehicles into BP 22, BP 25 and BP 21 while ensuring each could engage into designated engagement areas (EAs). The support for this change comes from two sources: the BLUEFOR commander's concept of the operation, and guidance in the Army Field Manual FM 71-2 The Tank and Mechanized Infantry Battalion Task Force [Ref. 6].

Figures 9, 10 and 11 depict the new positions assigned to vehicles in Battle Positions (BPs) BP 22, BP 25, BP 21. These new vehicle positions constitute changes to the basic scenario, but are not necessarily improvements in the BLUEFOR operation.

Figure nine shows Team A within Battle Position 22. Each vehicle can engage into engagement area (EA) Shark. Some vehicles had better fields of fire than did other vehicles.

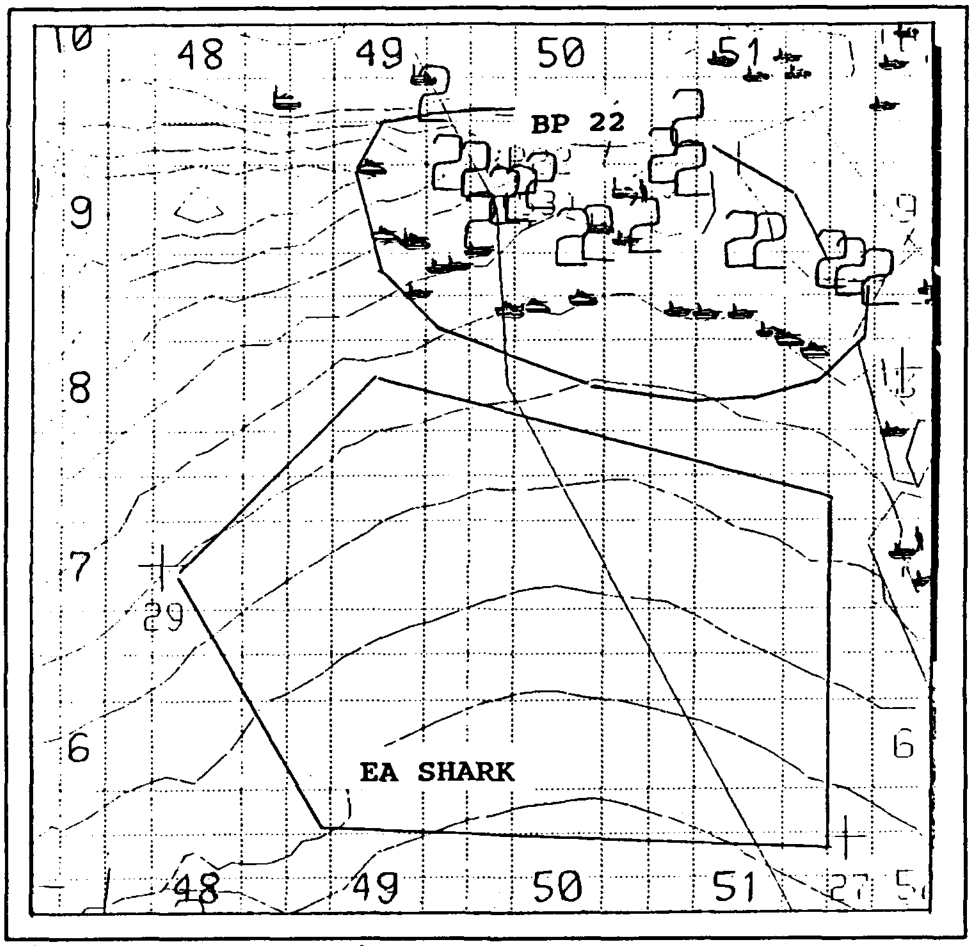

Figure 9 New Location of Team A

Figures ten and eleven show the new positions of D Co(-) and Team F respectively.

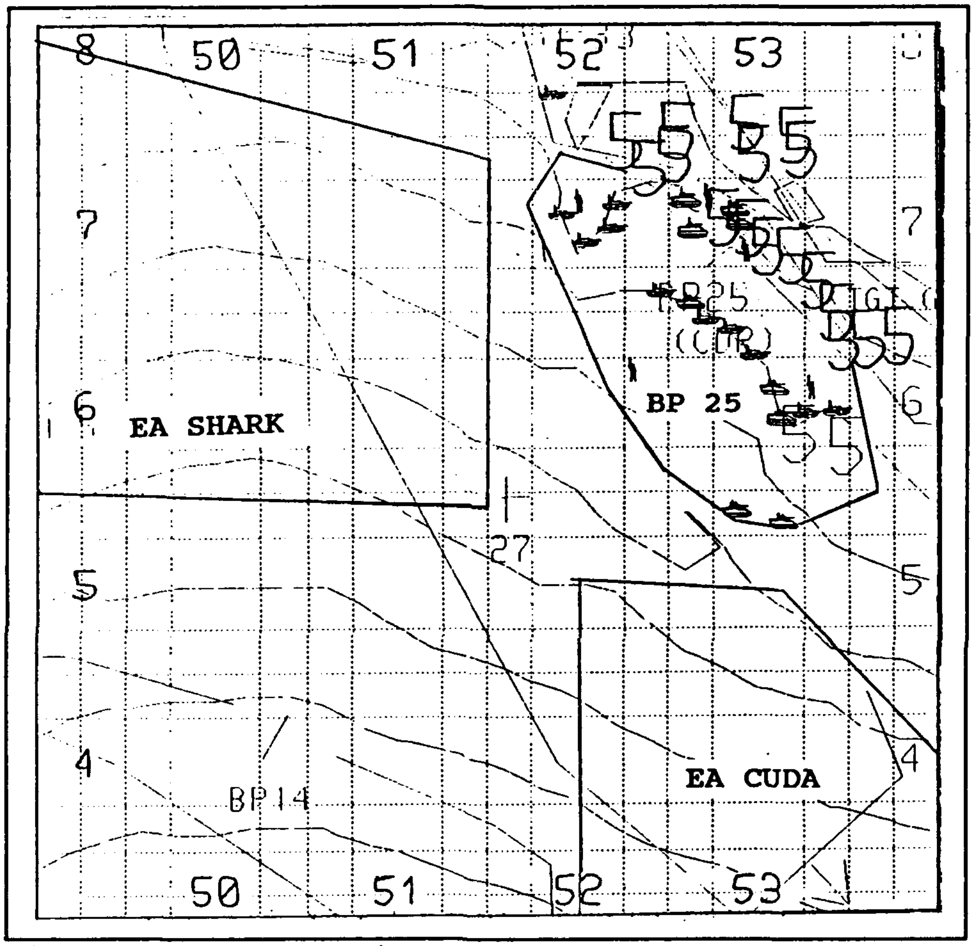

Figure 10 New Location of D Co (-)

During the qualification process many of the D Co(-) and Team F vehicles were given instructions to maneuver during the battle. The vehicle movements were based on the NTC battle. Part of this change in vehicle positions was to alter these routes. The alterations ensured the vehicles made roughly same movements, but each vehicle's movement began from the new vehicle position.

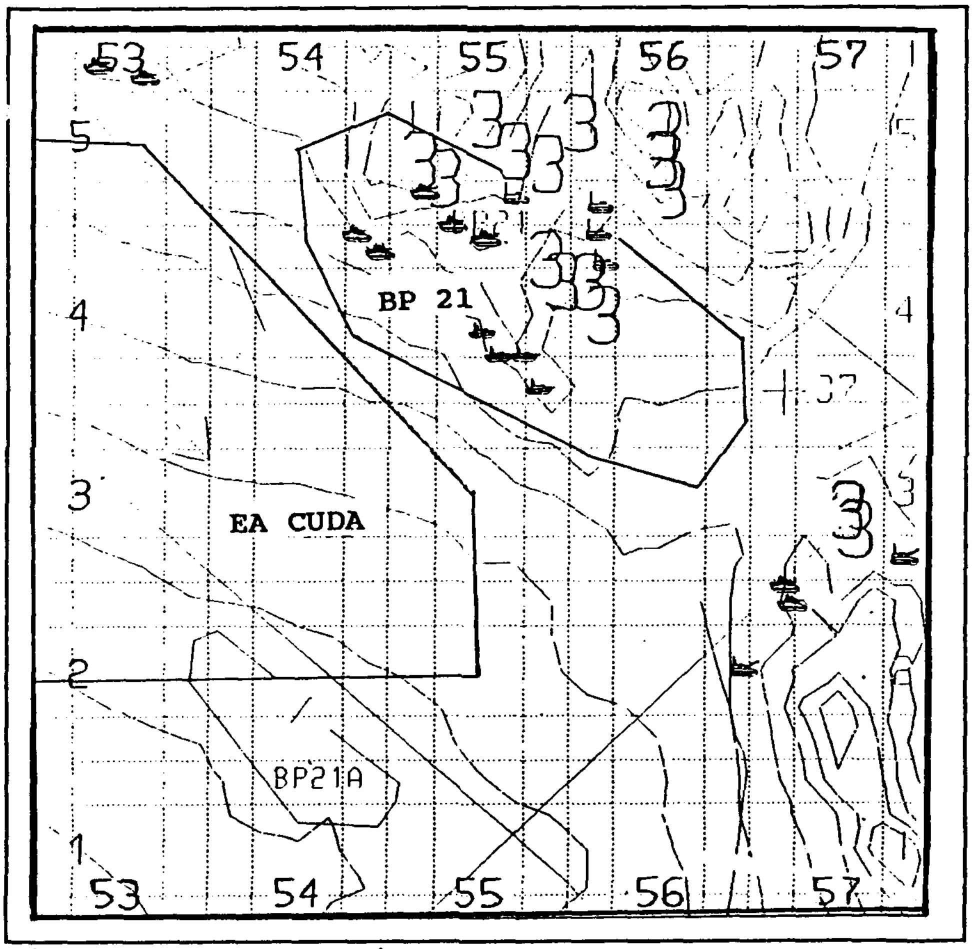

Figure 11 New Location of Team F

The commander's concept of the operation was to destroy the enemy in EA Shark and EA Piranha, and to prevent penetration of OPFOR forces [Ref. 5]. The lines of sight for each vehicle in Janus(A) were checked to ensure each vehicle could engage OPFOR elements in its primary EA. The guidance found in FM 71-2 is the basis for the arrangement of vehicles within the BPs [Ref. 6:pp.4-1 through 4-102]. This change to individual vehicle positions attempts to study the effects selecting different positions may have had on the battle outcome.

3. Survivability Position Parameter

As a result of the qualification process all vehicles in the simulation started in a partial defilade status [Ref.1:p. 38]. A partial defilade status simulates each vehicle in a fighting position that provides a medium amount of protection. The change considered in this thesis was to deploy vehicles in BP 21, BP 25 and BP 22 in a full defilade status. A full defilade status provides the vehicles with the maximum protection from enemy direct fire weapons. A full defilade position is equivalent to a hull-down fighting position. This change required the creation of 42 full defilade positions. Comments by the BLUEFOR engineer indicate that he attempted to emplace 42 survivability positions [Ref. 5]. The exact locations and extent to which any one position was used are not in the Take Home Package

(THP). This change was an attempt to study the effects that improved engineer support might have had on the battle.

4. Volume of Fire Parameter

The THP indicated that 24 BLUEFOR vehicles did not fire during the battle [Ref. 5]. Vehicles that fired zero rounds at the NTC were placed in a hold-fire status during the qualification process [Ref.1:p. 35]. A hold-fire status in Janus(A) prevents the vehicle from firing under any circumstance. The modification considered in this thesis is to change all those vehicles previously in a hold-fire status to a free-fire status. In a free-fire status the weapon may fire whenever the engagement criteria of the simulation are met. The modification to volume-of-fire in this thesis resulted in all vehicles being deployed in a free-fire status. This change is an attempt to determine the effect on the battle outcome with all the BLUEFOR vehicles capable of engaging targets.

5. Coordination of the Reserve Parameter

The BLUEFOR commander designated Team B as the BLUEFOR reserve. The changes in coordination of the reserve entailed adjusting the movement time and final vehicle positions of Team B. The new Team B arrival time to BP 31 was 10-15 minutes earlier than the arrival time in the basic qualified scenario. The final vehicle positions are all nearby Battle Position 31 (BP 31). Team B vehicles were oriented to the

West North-West from BP 31. Figure twelve shows the movement routes and final vehicle positions near BP 31.

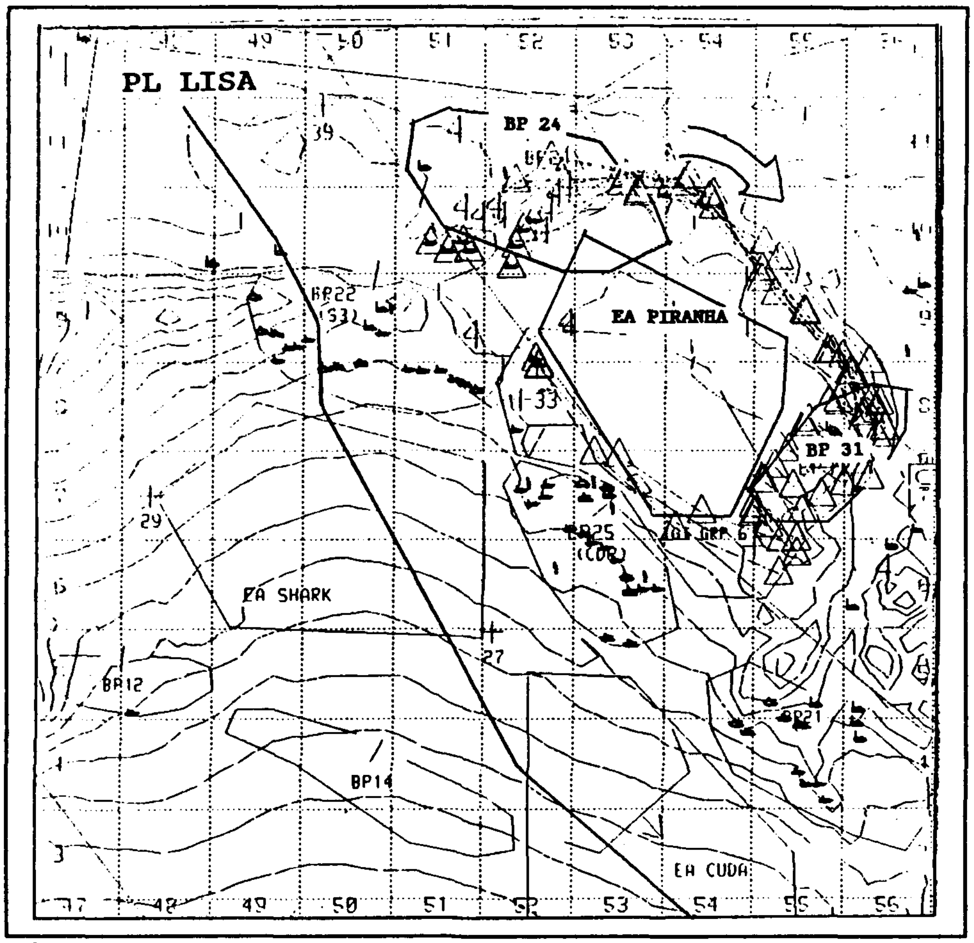

Figure 12 New Movement of Reserve, Team B

D. PART III. SELECTION OF AN EXPERIMENTAL DESIGN

1. General

A 2^K factorial experimental design was selected. This design is a subset of the family of factorial experimental designs. The name 2^K relates to considering K factors each with two levels. In this thesis K = 4.

The design was selected for several reasons. The 2^K design is particularly useful in the early stages of experimental work. The design allows the smallest number of treatment combinations with which K factors can be studied under a complete factorial arrangement. [Ref. 8:p. 192]

A 2^K design may provide information on how sensitive a response variable is to changes in main effects. This characteristic was important in assessing the impact changes in parameters had on the battle outcome. This design can provide insight into interactions between factors (main effects). Interactions occur when the difference in responses between levels of one factor is not the same at all levels of the other factors. [Ref. 8:pp. 189-292]

The final reasons for selecting a 2^K factorial design were the values used for the parameters and the possible values for the MOP. The parameters could take on two values indicating one of two conditions. One value of the parameter indicated the original condition. A second value of the parameter indicated the changed condition. The values of the

MOP were on a ratio scale. A 2^K design accommodates these parameter and MOP values. A discussion of the actual parameter values and the ranges for MOP values is given in section III F.

2. Discussion of the 2^4 Factorial Design

The 2^4 design is a special case of the general K-factor factorial design. The following equation models the relationship between the response variable and the four factors:

$$Y_{ijklm} = \mu+\tau_i+\beta_j+\gamma_k+\delta_l+(\tau\beta)_{ij}+(\tau\gamma)_{ik}+(\tau\delta)_{il} +(\beta\gamma)_{jk}+(\beta\delta)_{jl}+(\gamma\delta)_{kl} +e_{ijklm} ,$$

where:

i = 1,2;
j = 1,2;
k = 1,2;
l = 1,2;
m = 1,2,3,4,5;
n = 5, the number of observations for that combination of i, j, k, l;
Y_{ijklm} = mth response with corresponding factors at their i, j, k, l levels;
μ = overall mean response;
τ_i = effect of the ith level of factor A;
β_j = effect of the jth level of factor B;
γ_k = effect of the kth level of factor C;
δ_l = effect of the lth level of factor D;
and,
e_{ijklm} = the random error component.

In this thesis the factors A, B, C, and D correspond to the parameters. Terms of the form $(\tau\beta)_{ij}$ indicate the two-way

interactions of corresponding parameters (main factors). The values for i, j, k, and l are limited to 1 and 2 since this design only considers two levels of each factor. As discussed in section III F for this thesis, the total number of observations is 80. It is assumed that the e_{ijklm} are independent, identically distributed normal with a mean of zero and a variance σ^2. [Ref. 8:pp. 189-210]

The three and four-way interactions are assumed to be negligible and are not included in the model. All four main effects are considered to be fixed effects, because the level of each is not chosen at random. The four treatment effects are defined as deviations from the overall mean, so:

$$\sum_{i=1}^{2}\tau_i=0,\quad \sum_{j=1}^{2}\beta_j=0,\quad \sum_{k=1}^{2}\gamma_k=0,\quad \sum_{l=1}^{2}\delta_l=0\ .$$

The two-way interactions are also considered to be fixed effects. This results in equations relating the interaction effects. The following are examples of these equations:

$$\sum_{i=1}^{2}(\tau\beta)_{ij}=\sum_{j=1}^{2}(\tau\beta)_{ij}=0,$$
$$\sum_{i=1}^{2}(\tau\gamma)_{ik}=\sum_{k=1}^{2}(\tau\gamma)_{ik}=0\ .$$

Similar relationships are assumed for the remaining two-way interaction terms. [Ref. 8:pp. 45, 223-228]

The model accuracy depends on the assumption that the error terms, ϵ_{ijkl}, are normally distributed and independent. If the errors are from this normal distribution, then a normal probability plot of the model's error values should appear similar to the plot of a random sample from a normal distribution with the same mean and variance. Additionally, the behavior of the residuals may be examined by plotting each residual against the value predicted by the fitted linear model. This plot can be used to check for the presence of a relationship between the magnitude of the residual and the predicted value. For example, if the residual values increase as the predicted values increase then the model may not be adequate. [Ref. 8:pp. 201-206]

E. PART IV. SELECTION OF A MEASURE OF PERFORMANCE (MOP)

Part IV of the process resulted in the selection of two Measures Of Performance (MOPs). The first MOP (referred to as MOP1) is defined:

$$MOP1 = \frac{BLUEFOR\ \ ROUNDS\ \ FIRED}{OPFOR\ \ LOSSES} \quad .$$

Use of the rounds-per-kill measure at the NTC motivates using MOP1 in this thesis. This MOP may allow comparisons to be made between the NTC battle results and the results from the Janus(A) scenarios. These comparisons are tempered by the results of the TRAC-Monterey Technical Report concerning

differences in attrition between Janus(A) and the NTC [Ref. 1:pp. 56-58].

The second MOP is a combined measure of the fractions of OPFOR losses and BLUEFOR survivors. This MOP is labeled MOP2 and is defined by:

$$MOP2 = \frac{OPFOR\ LOSSES}{INITIAL\ OPFOR\ STRENGTH} + \frac{BLUEFOR\ SURVIVORS}{INITIAL\ BLUEFOR\ STRENGTH} .$$

MOP2 was selected for its relationship to the BLUEFOR mission of destroying OPFOR elements while preserving the BLUEFOR. The first term is a measure of how many OPFOR elements were destroyed by the BLUEFOR. The second term is a measure of how well the BLUEFOR commander was able to preserve his force.

MOP2 can range in values from zero (0) to two (2). At the start of a battle the value of MOP2 equals 1. The first term is 0 and the second term is 1. MOP2 equals 2 if the BLUEFOR commander has destroyed 100% of the OPFOR while preserving 100% of the BLUEFOR. An MOP2 value of 2 is the best the BLUEFOR can achieve. If 100% of the OPFOR survive and 100% of the BLUEFOR are destroyed, then the value of MOP2 equals 0. [Ref. 7:p. 39]

Values of MOP1 were calculated using total BLUEFOR rounds fired and OPFOR kills at the conclusion of each battle. MOP2 values were determined at the 120.0 minute point of each battle and at the conclusion of each battle. Support for selecting the 120.0 minute point for MOP2 is given in the

TRAC-Monterey Technical Report [Ref. 1:p. 13]. That report determined that the largest direct fire intensity occurred at approximately 120.0 minutes into the Janus(A) simulation. This corresponds to the time when the OPFOR 2nd Echelon engaged the main BLUEFOR elements near EA Cuda. The calculation of MOP2 at the 120.0 minute point in the battle and at the conclusion of the battle permits an investigation of how MOP2 behaves at a two points in the battle.

To prevent confusion between the two MOP2 values for each Janus(A) battle, the following naming conventions were used:

1. MOP2A is the MOP2 value determined at 120.0 minutes into a Janus(A) battle, and;
2. MOP2B is the MOP2 value determined at the conclusion of a Janus(A) battle.

These MOP definitions and naming conventions result in three MOP values for each Janus(A) battle.

F. PART V. CONDUCT OF THE EXPERIMENT

1. General

The 2^4 factorial design is the cornerstone of the experiment. The factorial design was used three times during this thesis; once for each MOP. A complete replicate of a 2^4 design requires 16 cells [Ref. 8:p. 261]. In this thesis the cells are groupings of Janus(A) battles. Each cell relates only to those Janus(A) battles executed under the same parameter levels. Five Janus(A) runs (replicates) were conducted for each of the 16 cells. So n = five in the 2^4

design discussed in III D. This requires a total of 5 x 16 = 80 Janus(A) runs. The time available for this thesis limited the number of Janus(A) runs to 80.

2. Construction of the 16 Janus(A) Scenarios

Each of the 16 Janus(A) scenarios were prepared at the TRAC-Monterey facility. There is one scenario for each of the 16 cells in the 2^4 design. The qualified NTC battle scenario in the TRAC-Monterey technical report was one of the 16 scenarios. This scenario is the base case scenario. The Janus(A) files for the base case scenario were copied and then modified to generate the other 15 scenarios.

Each of the 16 scenarios was assigned a unique four-digit code. This code represents the level of each parameter in the scenario. For example, a code of "1111" represents the base case scenario. Each of the four digits is limited to the values "1" or "2". A value of "1" indicates that the parameter level was not changed from the base case. A value of "2" indicates that the corresponding parameter has been changed. The order of the parameters represented in the four-digit code is survivability positions (SP), volume of fire (VF), vehicle positions (VP) and coordination of the reserve (CR). Table VII shows the four-digit codes with a brief explanation of changes.

Table VII CODES FOR THE 16 JANUS(A) SCENARIOS

TREATMENTS SP	VF	VP	CR	JANUS(A) SCENARIO	EXPLANATION OF CHANGE CODE
1	1	1	1	760	Base Case
1	1	1	2	768	Coordination of Reserve
1	1	2	1	764	Vehicle Positions for Tm A, D Co(-), Tm F
1	1	2	2	772	Vehicle Positions and Coordination of Reserve
1	2	1	1	761	Volume of Fire
1	2	1	2	769	Volume of Fire, Coordination of Reserve
1	2	2	1	765	Volume of Fire, Vehicle Positions
1	2	2	2	775	Vehicle Positions, Volume of Fire, Coordination of Reserve
2	1	1	1	762	Survivability Positions
2	1	1	2	771	Survivability Positions, Coordination of Reserve
2	1	2	1	766	Survivability, Vehicle Positions
2	1	2	2	773	Survivability, Vehicle Positions, Coordination of Reserve
2	2	1	1	763	Survivability, Volume of Fire
2	2	1	2	770	Survivability, Volume of Fire, Coordination of Reserve
2	2	2	1	767	Survivability, Vehicle Pos, Volume of Fire
2	2	2	2	774	Survivability, Vehicle Positions, Volume of Fire, Coordination of Reserve

3. Systemic Operation of Janus(A)

The 80 Janus(A) battle scenarios were conducted using the systemic processing feature in Janus(A). The steps used to execute each run were the same as those used in the TRAC-Monterey Technical Report [Ref. 1:p. 41]. This includes reducing possible correlation between runs by randomly selecting the initial random number seed for each scenario.

4. Processing Data from Janus(A) Systemic Runs

FORTRAN programs were written to process the post-Janus(A) simulation data. These FORTRAN programs generated two types of output files. One file contained information related to a particular Janus(A) runs. The second file contained information pertaining to each of the 80 battles.

Three files provide the input for these FORTRAN programs. Two of the input files are generated from the Janus(A) simulation data conversion processor. These two files are data files normally used as input to the LLNL AWS. These files contain information on kills and direct fire events. The third input file was the data file generated by the FORTRAN program developed at TRAC-Monterey.

5. Preparation of Post-Janus(A) Battle Data for Analysis

The STATGRAPHICS statistical software package was used in the conduct of this thesis [Ref. 9]. The files generated by the FORTRAN programs were in a format easily imported into STATGRAPHICS.

Four variables were created in the STATGRAPHICS work space. There was a variable for each of the parameters varied in the BLUEFOR. Each variable contained 80 values. Each of the 80 values represented the level code for one of the Janus(A) runs, so the variables were one-dimensional arrays consisting of ones and twos. The variables were used to represent the main effect values for the 2^4 factorial design and to assist the creation of plots in STATGRAPHICS.

IV RESULTS OF THE JANUS(A) SENSITIVITY ANALYSIS

A. GENERAL

The results of the sensitivity analysis are discussed under two parts. The first part concerns results attributed to an exploratory data analysis. This exploratory analysis pertained to all 80 values generated for each MOP. The creation and analysis of notched-boxplots are major portions of this exploratory data analysis.

The second part concerns results credited to the 2^4 factorial design discussed in Chapter III. These results include a discussion of how changes in the parameters (main effects) affected MOP values and a discussion of how interactions between parameters affected the MOP.

B. RESULTS FROM THE EXPLORATORY DATA ANALYSIS

1. General

The exploratory data analysis did not provide information to dispute the validity of the 2^4 factorial design. Also, the exploratory analysis indicated that MOP1 was less sensitive to changes in the parameters than was MOP2.

The exploratory data analysis focused in the following two areas for each MOP. One area was in the appreciation of variation in the MOP values. This appreciation of the data

came mainly from the information contained in notched-boxplots. A notched-boxplot is a graphical display of one dimensional data. The notched-boxplot shows a measure of location (median), two measures of dispersion (interquartile range and a confidence interval for the median) and an indication of skewness (whiskers and the presence of outliers). [Ref. 10:pp. 336-338]

The second area of the exploratory analysis concerned the assumed homogeneity of variance required by the 2^4 design. This assumption warranted consideration in the exploratory data analysis since the factorial model is sensitive to deviations from homogeneity of variance. The test for homogeneity in variance involves the test statistic C [Ref. 11:pp. 61-62, 537]. The test statistic is defined as C:

$$C = \frac{MAX_i \hat{\sigma}_i^2}{\sum_{i=1}^{16} \hat{\sigma}_i^2} \quad ,$$

where $\hat{\sigma}_i^2$, i=1,2,...,15,16, are the sample variances.

2. MOP1

Recall that MOP1 is defined as:

$$MOP1 = \frac{BLUEFOR\ ROUNDS\ FIRED}{OPFOR\ LOSSES} \quad .$$

The notched-boxplots for the values of MOP1 indicated that MOP1 was not responsive to changes in the four parameters.

This indication comes from the overlapping of many of the notches. Since the notches respresent 95% confidence intervals for the medians, these notched-boxplots indicate overlapping of the confidence intervals for medians.

Figure 13 contains 16 notched-boxplots. There is one notched-boxplot for each of the 16 cells. The boxplots are for the five MOP1 values corresponding to one combination of parameter levels. The boxplots are labeled by their respective four-digit codes.

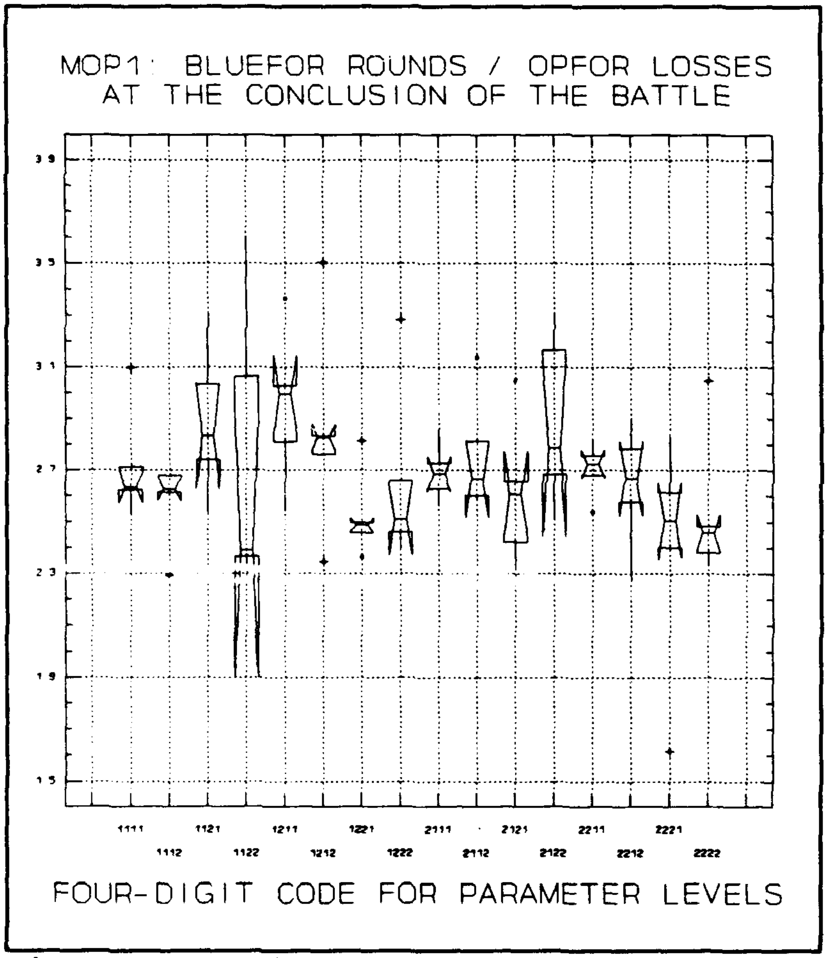

Figure 13 Multiple Notched-Boxplots for MOP1

The median values of MOP1 range from 2.458 for code 2222 (changes applied to all four parameters) to a high of 2.993 for cell 1211 (changes to volume-of-fire only). These values equate to roughly 2.5 and 3.0 rounds-per-kill. One reason for this small spread in median MOP1 values may be the processing of direct-fire engagements in Janus(A). The following is a discussion to support this view.

Consider one engagement between one firing vehicle and one target. During this engagement the firing vehicle is a BLUEFOR vehicle in a stationary position. Again, the Janus(A) Single-Shot-Kill-Probability is:

$$SSKP = Pr(Kill \mid Range,\ Weapon,\ Target\ Posture) \times$$
$$Pr(Hit \mid Range,\ Weapon,\ Firer\ and\ Target\ Posture)\ .$$

Let us assume that this engagement takes place over a relatively short time span. A span of time short enough that the range to target has not changed more than a few hundred meters. In this scenario the average off-road movement rate was 17 kilometers-per-hour [Ref. 1:p. 25]. It is not unreasonable for an engagement to be completed without the range changing more than a few hundred meters.

Referring to the hypothetical kill curve in Chapter II, the probability-of-kill does not change greatly for a few hundred meter change in range, unless of course the change in range takes place across the minimum or maximum ranges. This

extreme case at the range limits is not considered. The rate of change for probability-of-kill curves are similar to those for probability-of-hit curves.

In this engagement sequence the firing vehicle fires until it registers a kill. This is approximately equivalent to a series of independent Bernoulli trials where the firing system stops engaging after the first success [Ref. 10:p. 34]. The probability of a success in each of these trials equals the SSKP value.

None of the parameter changes involved changing the probability-of-hit or probability-of-kill for any weapon. This "insulation" of the SSKPs from parameter changes may account for the lack of response in MOP1.

There was no indication of heterogeneity of variance among the 16 cells for MOP1. Results from the test for homogeneity of variance failed to support rejection of the hypothesis that the cell variances are equal. Table VII contains a summary of the test [Ref. 11:p. 537].

Table VIII HOMOGENEITY OF VARIANCE TEST, MOP1

C Test For Homogeneity of Variance. MOP1			
MAX $\hat{\sigma}_i^2$	$\Sigma\ \hat{\sigma}_i^2$	C Test Value	Critical Value: α = 0.05, k = 16, n = 5
0.32753	1.53196	0.2137	≈ 0.2419*

* value for k = 15

The hypotheses under this test for equal variances were,

$$H_O : \sigma_1^2 = \sigma_2^2 = \cdots = \sigma_{15}^2 = \sigma_{16}^2 \text{ , and}$$
$$H_A : \text{some } \sigma_i^2 \text{ 's are unequal} \quad ,$$

where σ_i^2 are the variances of the response variable in the 16 cells. The H_0 hypothesis is not rejected if the test statistic C is below the critical value. The test statistic has an F distribution with k and n-1 degrees of freedom. The value of k equals the number of variances and n is the number of observations in each cell. For the experiment in this thesis k equals 16 and n equals five. [Ref. 11:p. 61]

3. MOP2A and MOP2B

The general form of MOP2 is:

$$MOP2 = \frac{OPFOR\ LOSSES}{INITIAL\ OPFOR\ STRENGTH} + \frac{BLUEFOR\ SURVIVORS}{INITIAL\ BLUEFOR\ STRENGTH} .$$

Figures 14 and 15 contain multiple notched-boxplots for MOP2A and MOP2B respectively. In contrast to MOP1, the values for

MOP2 appear to respond to changes in the four parameters. The combinations of parameter levels that included the volume-of-fire parameter (second digit of code) at level 2 generally had high MOP2 values. Level 2 for volume-of-fire reflects all BLUEFOR vehicles capable of engaging OPFOR elements.

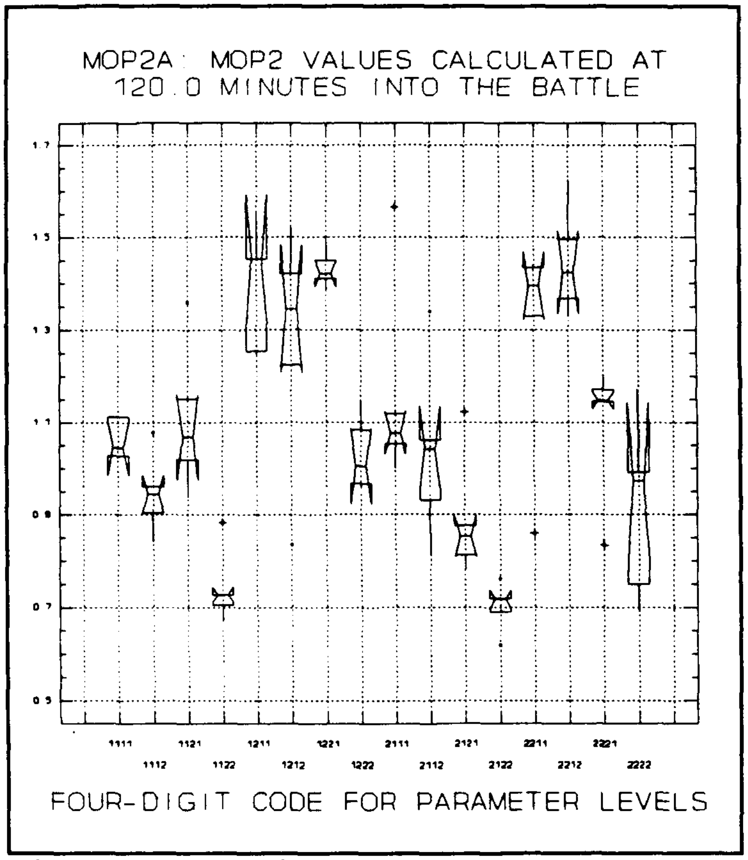

Figure 14 Multiple Notched-Boxplots for MOP2A

The median values for MOP2A range from 0.727 to 1.452. These median values are from cell 1122 (changes to vehicle positions and coordination of reserve parameters) and cell 1211 (changes to volume-of-fire only), respectively. The extremes in variance occurred in cell 1212 (changes to volume-of-fire and coordination of the reserve) and cell 1221 (changes to volume-of-fire and vehicle positions).

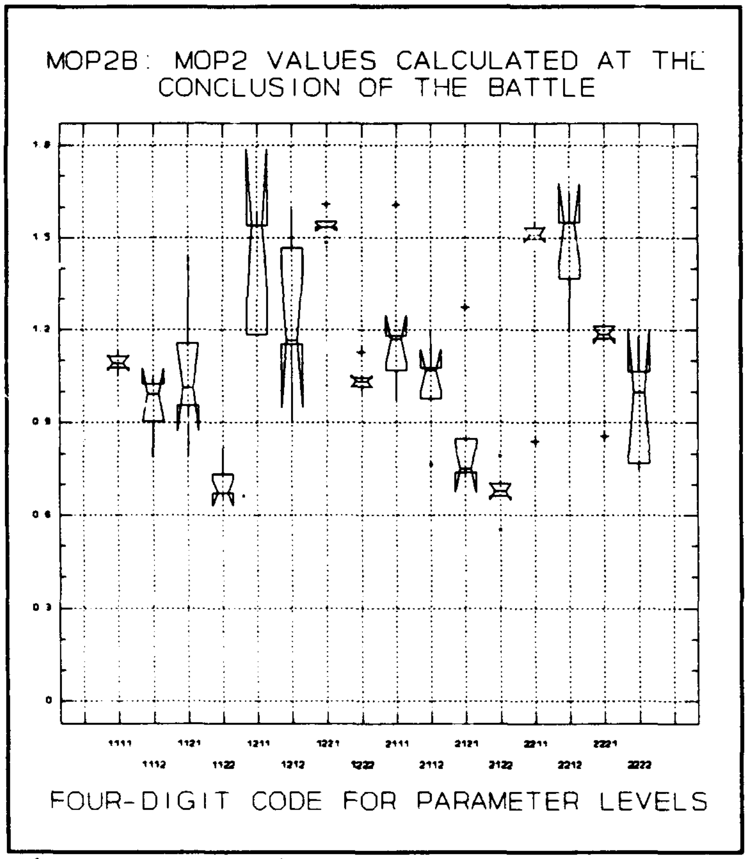

Figure 15 Multiple Notched-Boxplots for MOP2B

The extreme median values for the cells of MOP2B are 1.549 for cell 2212 (changes to all parameters except vehicle positions) and 0.677 for cell 2122 (change to all parameters

except volume-of-fire). The range in variance values among the three MOPs is largest for MOP2B. The variances ranged from 0.00118 in cell 1111 (base scenario, no changes) to a high of 0.07601 in cell 1212 (changes to volume-of-fire and coordination of the reserve).

The assumption for homogeneity of variance was not rejected by the C test results. The same hypotheses used for homogeneity of variance in MOP1 were used to test MOP2A and MOP2B values. The degrees of freedom were also the same. Tables IX and X contain the results of the C test. The hypothesis that the σ^2_i's are equal was not rejected for either MOP2A or MOP2B.

Table IX HOMOGENEITY OF VARIANCE TEST, MOP2A

C Test For Homogeneity of Variance. MOP2A			
MAX $\hat{\sigma}_i^2$	$\Sigma\ \hat{\sigma}_i^2$	C Test Value	Critical Value: $\alpha = 0.05$, $k = 16$, $n = 5$
0.0706	0.3863	0.18276	≈ 0.2419 *

* Value for k = 15

Table X HOMOGENEITY OF VARIANCE TEST, MOP2B

C Test For Homogeneity of Variance. MOP2B			
MAX $\hat{\sigma}_i^2$	$\Sigma\ \hat{\sigma}_i^2$	C Test Value	Critical Value: α = 0.05, k = 16, n = 5
0.09359	0.53142	0.17611	~ 0.2419 *

* Value for k = 15

C. RESULTS OF THE 2^4 EXPERIMENT

1. General

The results from the factorial experiment are in concert with the exploratory data analysis results. None of the changes in the four parameters caused a statistically significant response in MOP1. One interaction was shown to statistically affect MOP1. Both MOP2A and MOP2B demonstrated sensitivity to changes in the parameters and the presence of interactions.

The experiment was performed as discussed in Chapter III. The statistic used to evaluate the significance of main and interaction effects is a ratio of two variance estimates. This ratio is the F-ratio. The F-ratio compares mean square values associated with treatments and interactions to the residual mean square error.

An example of this F-ratio is:

$$F\ ratio = \frac{\dfrac{MEAN\ SQUARE_{VEHICLE\ POSITION}}{f}}{\dfrac{MEAN\ SQUARE\ ERROR}{e}}\ ,$$

where:

f = the degrees of freedom for vehicle position (= 1):

and,

e = the degrees of freedom for the residual error (= 69) [Ref 10:p. 418].

For each main effect (parameter) the degrees of freedom equal one. The degrees-of-freedom for each two way interaction in this model is one. The degrees-of-freedom for the residual error is defined by

$$\begin{gathered} RESIDUAL\ DEGREES\ OF\ FREEDOM = \\ TOTAL\ DEGREES\ OF\ FREEDOM \\ -\sum parameter\ degrees\ of\ freedom \\ -\sum interaction\ degrees\ Of\ freedom\ . \end{gathered}$$

In this thesis the total degrees-of-freedom is 80-1 = 79. The residual mean square error is associated with 79-4-6 = 69 degrees of freedom. [Ref. 10:p. 417]

The linear model discussed in Chapter III was:

$$Y_{ijklm} = \mu+\tau_i+\beta_j+\gamma_k+\delta_l+(\tau\beta)_{ij}+(\tau\gamma)_{ik}+(\tau\delta)_{il}$$
$$+(\beta\gamma)_{jk}+(\beta\delta)_{jl}+(\gamma\delta)_{kl}$$
$$+\epsilon_{ijklm} \quad .$$

Example hypotheses used in testing each main factor effect in this model are of the form:

$$H_O : \tau_1 = \tau_2 = 0 \quad ; \textit{and,}$$
$$H_A : \tau_1 \neq \tau_2 \quad .$$

H_0 is equivalent to stating the parameter associated with τ has no effect on the mean of Y_{ijklm} values. The hypothesis is rejected if the F ratio value is above a critical value. The critical value is based upon the same degrees of freedom as the F ratio, but is associated with the probability that H_0 is rejected when it is true. This probability is the type-one error, normally denoted by α [Ref. 10:p. 272]. Typical values for α are 0.05 and 0.01. In this thesis, α is taken to be 0.05. The following sections discuss the specific results of the 2^4 factorial experiment for each MOP.

2. MOP1

The factorial experiment did not demonstrate the presence of a relationship between the changes in parameters and the mean values of MOP1. This is consistent with the

earlier data analysis (Section IV B). The hypotheses that the parameters do not affect the mean MOP1 values were not rejected. The experiment did indicate the presence of a significant interaction that affected MOP1. This interaction occurred between the volume-of-fire parameter and the vehicle position parameter. Table XI contains a summary of the analysis of variance for MOP1.

Table XI SUMMARY OF RESULTS, MOP1

Experimental Results: MOP1 = Rounds per Kill						
SOURCE	SUM OF SQUARES	DEG. OF FREE.	MEAN SQ.	F-RATIO	SIG. LEVEL	REJECT H_0
MAIN EFFECTS	.40579	4	.1014	1.1	.3635	
SURVIVABILITY POSITIONS	.14645	1	.1464	1.588	.2113	NO
VOLUME OF FIRE	.1170	1	.1170	1.269	.2638	NO
VEHICLE POSITIONS	.1314	1	.1314	1.425	.2366	NO
COORDINATION OF RESERVE	.0109	1	.0109	.118	.7356	NO
TWO-WAY INTERACTIONS	1.064	6	.1773	1.923	.0892	
SURVIVABILITY - VOLUME OF FIRE	.1686	1	.1686	1.829	.1807	NO
SURVIVABILITY - VEHICLE POSITION	.0022	1	.0022	.024	.8785	NO
VOLUME OF FIRE - VEHICLE POSITION	.6189	1	.6189	6.706	.0117	YES
SURVIVABILITY - COORD OF RESERVE	.1416	1	.1416	1.536	.2194	NO
VOLUME OF FIRE - COORD OF RESERVE	.0013	1	.0013	.015	.9055	NO
VEHICLE POSITION - COORD OF RES	.1319	1	.1319	1.431	.2357	NO
RESIDUAL	6.362	69	.0922			
TOTAL	7.8319	79				

Figure 16 contains a plot of mean values of MOP1 against levels of the vehicle position parameter. The solid line corresponds to the volume-of-fire parameter at level one, and the dashed line is for volume-of-fire at level two. Each mean value is based on the 20 MOP values corresponding to that combination of the two parameters.

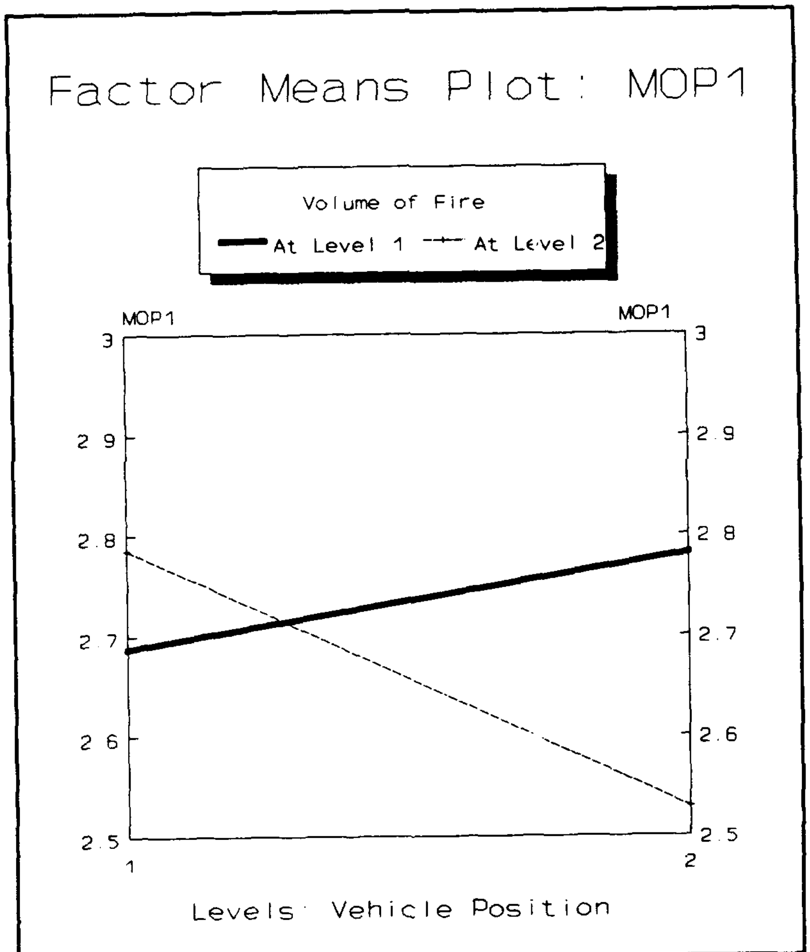

Figure 16 Plot of Means for Interaction, MOP1

Figure 16 suggests that the effect of changing vehicle position from level one to level two depends on whether volume-of-fire is at level one or two. With the volume-of-fire parameter at level one, changing vehicle position to level two is beneficial in terms of MOP1. A low value of MOP1 (rounds-per-kill) is preferred.

An investigation of the values comprising MOP1 provides the basis for one explanation of this interaction. More BLUEFOR rounds are fired when volume-of-fire is at level two (a mean rounds fired of 393 verses 301 for level one). It appears that the new vehicle positions allow the BLUEFOR to expend fewer rounds while causing similar OPFOR losses. With respect to the four mean values in this interaction, the mean number of OPFOR losses range from 140 to 155.

3. MOP2A and MOP2B

Unlike MOP1, both MOP2A and MOP2B demonstrated statistically significant main factor effects. Tables XII and XIII contain analysis of variance results for MOP2A and MOP2B, respectively.

Table XII SUMMARY OF RESULTS, MOP2A

Experimental Results: MOP2A = OPFOR Casualty Rate + BLUEFOR Survival Rate, 120.0 minutes into the battle						
SOURCE	SUM OF SQUARES	DEG. OF FREE.	MEAN SQ.	F-RATIO	SIG. LEVEL	REJECT H_0
MAIN EFFECTS	3.0743	4	.7685	32.43	.0000	
SURVIVABILITY POSITIONS	.0607	1	.0607	2.565	.1138	NO
VOLUME OF FIRE	1.556	1	1.556	65.68	.0000	YES
VEHICLE POSITIONS	.8927	1	.8927	37.67	.0000	YES
COORDINATION OF RESERVE	.5643	1	.5643	23.81	.0000	YES
TWO-WAY INTERACTIONS	.7617	6	.1269	5.357	.0001	
SURVIVABILITY - VOLUME OF FIRE	.0281	1	.0281	1.185	.2801	NO
SURVIVABILITY - VEHICLE POSITION	.2992	1	.2992	12.69	.0007	YES
VOLUME OF FIRE - VEHICLE POSITION	.0068	1	.0068	.287	.5999	NO
SURVIVABILITY - COORD OF RESERVE	.1383	1	.1383	5.839	.0183	YES
VOLUME OF FIRE - COORD OF RESERVE	.0188	1	.0188	.794	.3854	NO
VEHICLE POSITION - COORD OF RES	.2703	1	.2703	11.41	.0012	YES
RESIDUAL	1.635	69	.0236			
TOTAL	5.4711	79				

Table XIII SUMMARY OF RESULTS, MOP2B

Experimental Results: MOP2B = OPFOR Casualty Rate + BLUEFOR Survival Rate, at the Conclusion of the Battle						
SOURCE	SUM OF SQUARES	DEG. OF FREE.	MEAN SQ.	F-RATIO	SIG. LEVEL	REJECT H_0
MAIN EFFECTS	3.6417	4	.9104	15.71	.0000	
SURVIVABILITY POSITIONS	.1353	1	.1353	2.335	.1310	NO
VOLUME OF FIRE	1.675	1	1.675	38.90	.0000	YES
VEHICLE POSITIONS	.7059	1	.7059	12.17	.0008	YES
COORDINATION OF RESERVE	1.125	1	1.125	19.41	.0000	YES
TWO-WAY INTERACTIONS	.5002	6	.0833	1.438	.2128	
SURVIVABILITY - VOLUME OF FIRE	.0878	1	.0878	1.515	.2225	NO
SURVIVABILITY - VEHICLE POSITION	.2129	1	.2129	3.673	.0595	NO
VOLUME OF FIRE - VEHICLE POSITION	.0425	1	.0426	.734	.4037	NO
SURVIVABILITY - COORD OF RESERVE	.0518	1	.0518	.8959	.3576	NO
VOLUME OF FIRE - COORD OF RESERVE	.0071	1	.0071	.123	.7307	NO
VEHICLE POSITION - COORD OF RES	.0979	1	.0979	1.689	.1980	NO
RESIDUAL	4.000	69	.0579			
TOTAL	8.1420	79				

The survivability position parameter was the only main effect that did not demonstrate a statistically significant effect on mean values of MOP2A or MOP2B. The results for MOP2A indicated significant interaction among three of the parameters.

Figures 17, 18 and 19 are plots of mean MOP2A values. Each plot depicts one of the significant two-way interactions. The format for these three plots is the same as discussed for the MOP1 interaction. Figure 17 suggests that MOP2A decreases when the vehicle position parameter is changed to level two, and the decrease is more pronounced when survivability is at level two.

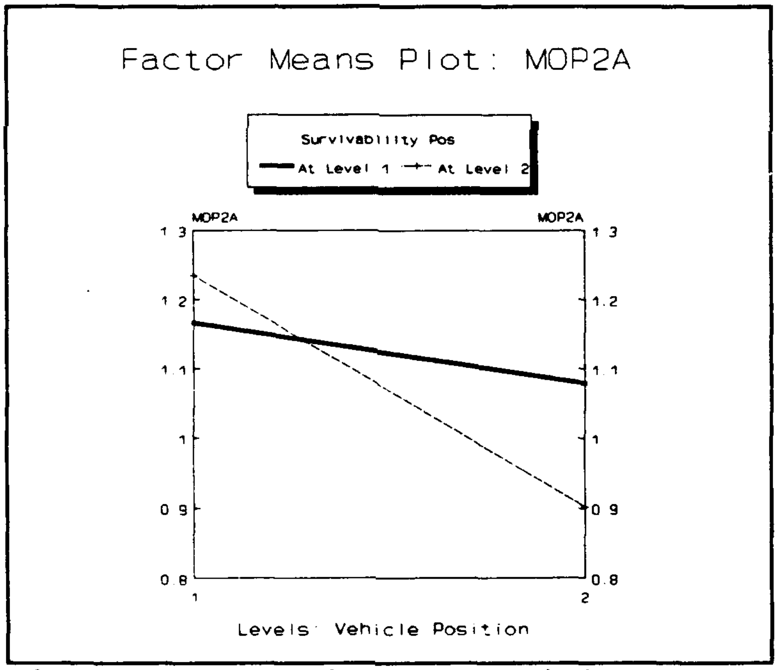

Figure 17 Vehicle Position and Survivability Position Interaction, MOP2A

Through inspection of the two terms (OPFOR Loss Rate and BLUEFOR Survival Rate) of MOP2A it appears that the emplacement of survivability positions can not overcome the BLUEFOR vulnerability introduced by the new vehicle positions. The fact that many BLUEFOR vehicles maneuver throughout the battle may have degraded the effectiveness of the selected survivability positions.

Figure 18 reflects the interaction between the coordination of reserve and survivability position parameters. The effect of changing the coordination of reserve parameter to level two is smaller when the survivability parameter is at level two. Both terms of MOP2A decrease when the coordination of reserve parameter is changed to level two, but decreases in both terms are smaller when the survivability position parameter is at level two. With coordination of reserves at level two, it appears that adding these survivability positions allows the BLUEFOR to kill more OPFOR vehicles while suffering fewer losses.

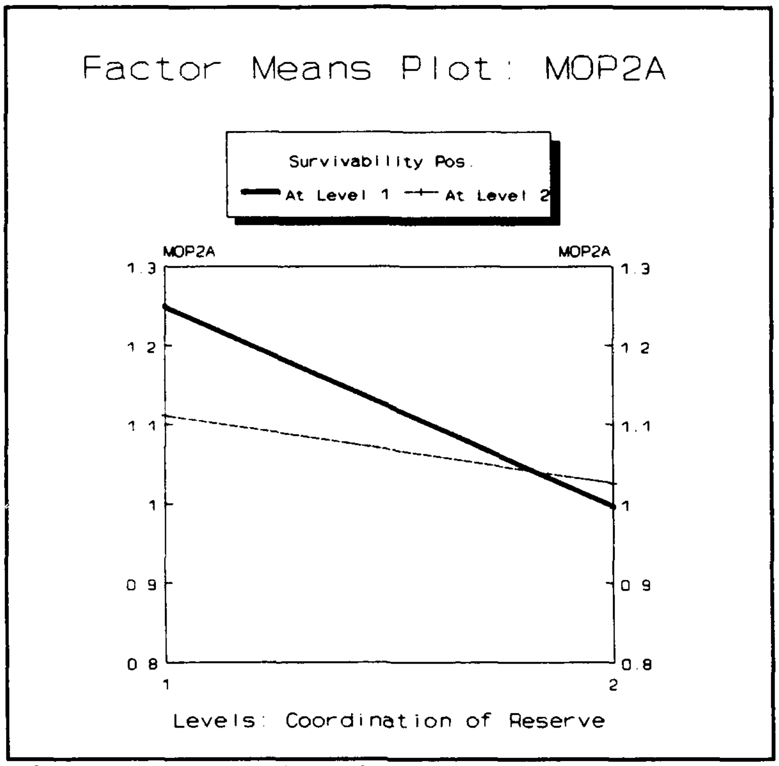

Figure 18 Survivability and Coordination of Reserve Interaction, MOP2A

Figure 19 contains a plot showing interaction between vehicle position and coordination of reserve parameters for MOP2A. Holding both the coordination of the reserve and the vehicle position parameters at level one results in a higher mean MOP2A value. In this combination both the OPFOR loss and the BLUEFOR survival rates are higher. Comparisons of the two terms in MOP2A indicate that lower BLUEFOR survival rates are associated with the coordination of the reserve parameter at level two. Under this interaction, holding the vehicle position parameter at level one may allow an earlier attrition

of OPFOR vehicles while presenting a lower risk to BLUEFOR vehicles involved in the reserve.

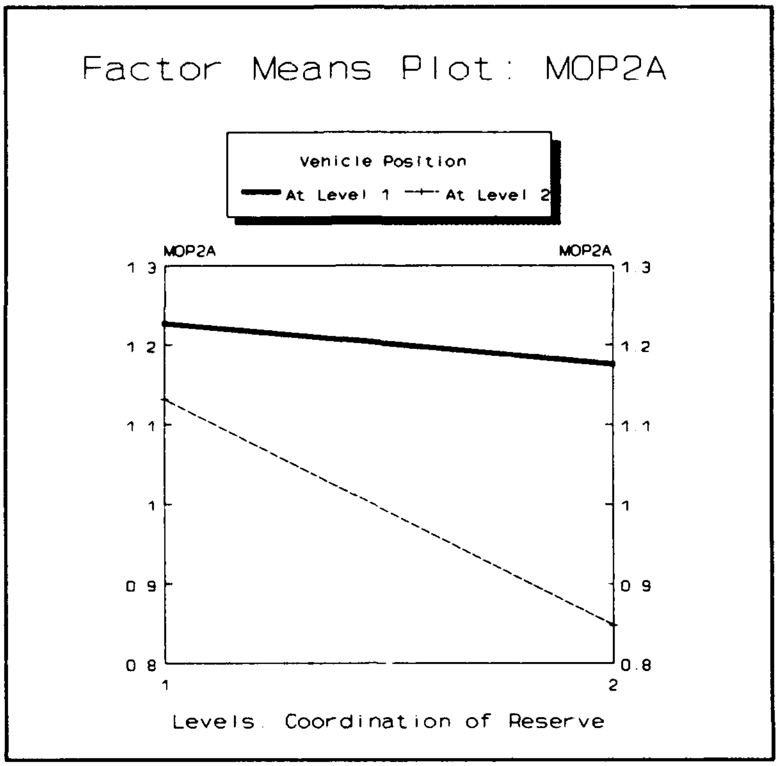

Figure 19 Vehicle Position and Coordination of Reserve Interaction, MOP2A

4. Model Adequacy: Residual Analysis

Residual analyses included plotting the model's residuals against predicted MOP values and making a normal-normal plot of residuals against $N(0,\sigma^2)$ random samples. The variance of the random samples was set equal to the variance of the residuals. The residual analyses supported the normality and homogeniety assumptions of our model. Figures

20 and 21 show scatter plots of residual values against predicted values for MOP1 and MOP2A.

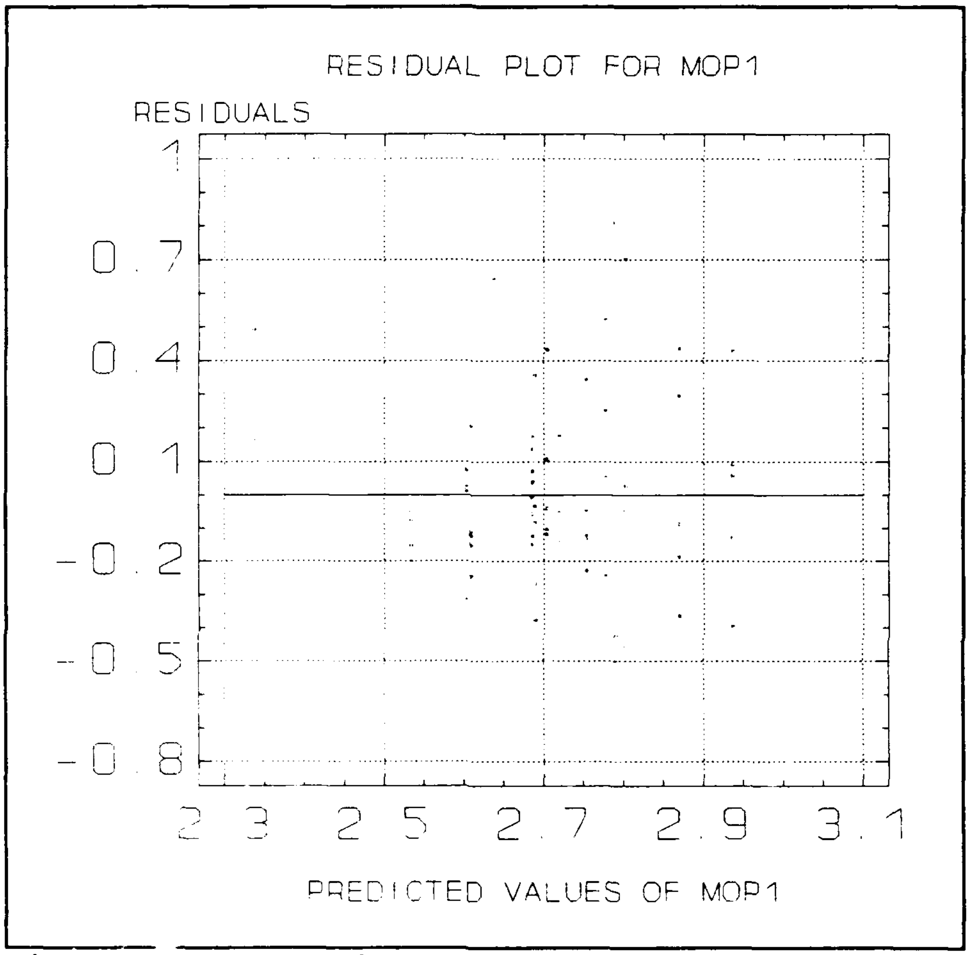

Figure 20 MOP1 Residuals

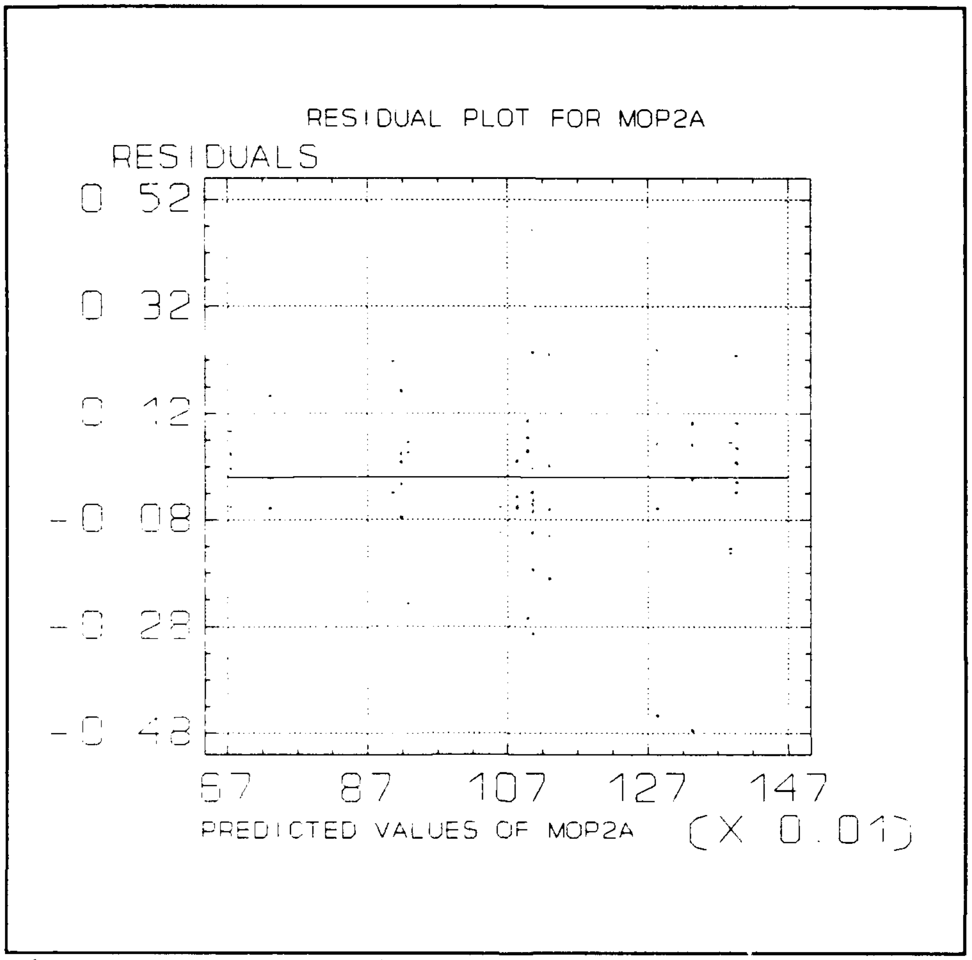

Figure 21 MOP2A Residuals

Figure 22 shows a cumulative probability plot of the residuals for MOP1. This plot is similar to cumulative probability plots for the other MOPs. The horizontal axis represents the residual values. The vertical axis is scaled so that the cumulative distribution function (cdf) of a normal distribution would plot along the solid line shown in the body of the graph.

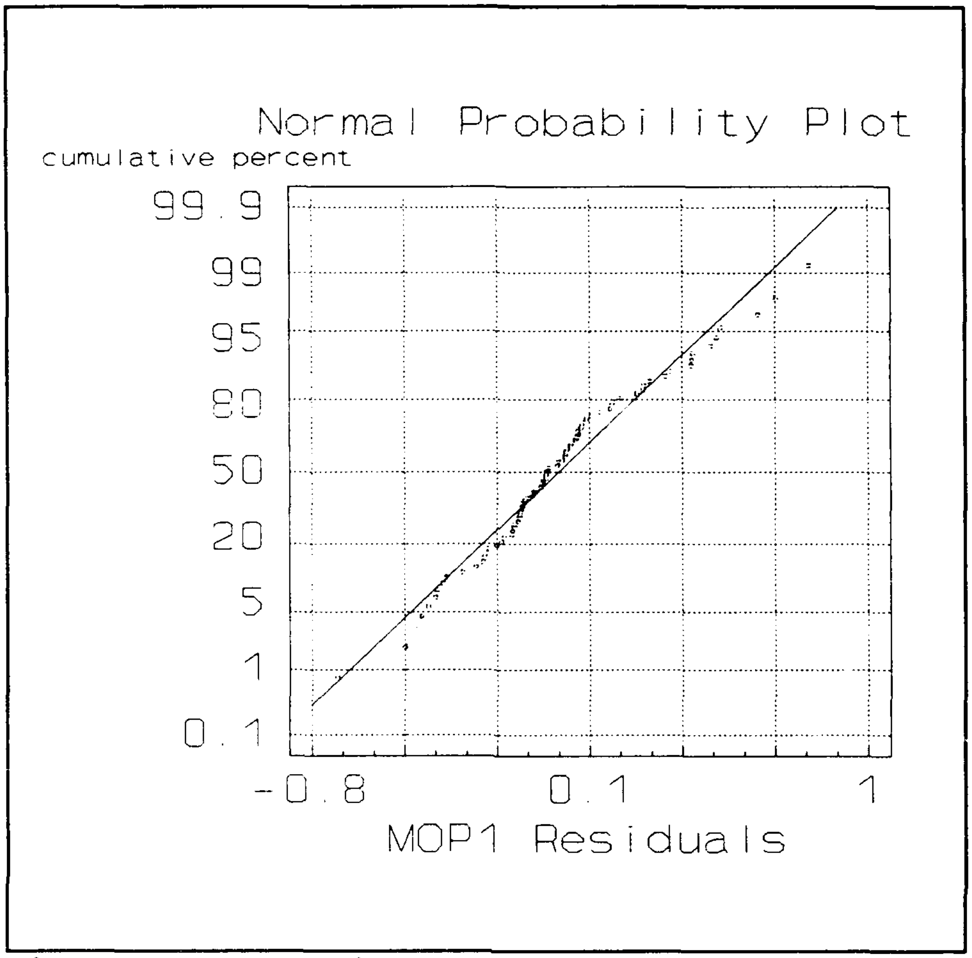

Figure 22 Cumulative Probability Plot for MOP1 Residuals

V CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY AND CONCLUSIONS

Progress was made in accomplishing each primary objective of this thesis. The analysis indicates that under certain conditions the output of the Janus(A) model is sensitive to changes in battle parameters. Janus(A) sensitivity was defined in terms of the changes in battle parameters that resulted in changes in mean Measure Of Performance (MOP) values. The analysis discussed in this thesis suggests that the amount of sensitivity demonstrated by Janus(A) is a function of two items:

1. the Measure Of Performance (MOP) used as model output; and,
2. the battle parameters (main effects) that are modified in a battle.

The battle parameters in terms of BLUEFOR were,

1. survivability positions;
2. vehicle positions;
3. volumes-of-fire; and,
4. coordination of the reserve.

In this thesis Janus(A) did not demonstrate statistically significant sensitivity for output of the form

$$MOP1 = \frac{BLUEFOR\ ROUNDS\ FIRED}{OPFOR\ LOSSES} \quad .$$

The second form of model output considered in this thesis was MOP2,

$$MOP2 = \frac{OPFOR\ LOSSES}{INITIAL\ OPFOR\ STRENGTH} + \frac{BLUEFOR\ SURVIVORS}{INITIAL\ BLUEFOR\ STRENGTH} \quad .$$

Janus(A) demonstrated statistically significant changes in MOP2 with respect to three of the four parameters. Only the survivability position parameter (as a main effect) failed to demonstrate a statistically significant effect on mean MOP2 values.

Janus(A) indicated the presence of interactions among the three of the four battle parameters with MOP2 as the model output. Volume-of-fire was the only battle parameter that was not included in a significant two-way interaction.

The sensitivity of Janus(A) output to changes in battle parameters demonstrates potential for using Janus(A) in the post-NTC training environment. A commander could use Janus(A) to help predict how tactical changes may affect battle outcome. The NTC provides results on how well the unit performed under the conditions present at the NTC. With a qualified battle implemented in Janus(A), the commander could alter the conditions that were present at the NTC and obtain

predictions of how these changes might have affected the battle.

The results of this thesis may prove beneficial to TRAC-Monterey during phase III of the Janus and NTC Comparison Study. The indications of sensitivity in Janus(A) suggest the model could be a practical training asset.

B. RECOMMENDATIONS

Three recommendations are made concerning,

1. the potential data collection effort at the NTC;

2. the need for further analysis concerning the sensitivity of the Janus(A) simulation; and,

3. the further development of the NTC-Janus(A) training plan contained in the Appendix.

If the use of the Janus(A) simulation increases, the training potential for its use with NTC scenarios should not be overlooked. To capitalize on this training potential, the personnel at the NTC should consider collecting battle data that can facilitate training with Janus(A).

The sensitivity analysis in this thesis considered only one change in each of the four BLUEFOR parameters. With Janus(A) sensitivity demonstrated for only selected changes in these four parameters, it may prove helpful to investigate how sensitive Janus(A) output is to other changes in these and other parameters. Also, this thesis has demonstrated sensitivity for one Measure of Performance (MOP) with respect

to one NTC battle. It would be useful to investigate other MOPs and NTC battles.

The Appendix contains an outline of a training plan for use by a unit after it has completed an NTC training rotation. While this outline is short of being a complete battalion plan, it might be considered a basis for developing complete plans. The plan contains a process based on the conclusions of this thesis and those in the TRAC-Monterey technical report.

APPENDIX: A PLAN FOR USING JANUS(A) IN POST-NTC ROTATION TRAINING

A. PURPOSE

The purpose of this plan is to aid the commander in determining what effect changes to a plan might have had on the outcome of a previous NTC battle. The use of Janus(A) augments those actions normally taken by a commander to war game previous battles.

B. SCOPE

This plan pertains to NTC force-on-force (MILES-instrumented) missions executed at the NTC. This use of Janus(A) does not replace any method currently used to aid the commander in war gaming battles. Janus(A) should be used to help determine how changes in a plan affect battle outcome as measured by one or more Measures Of Performance (MOP's).

This plan has three objectives:

1. to provide a forum for the commander to review with subordinate leaders battles executed at the NTC;

2. to provide the commander with one estimate of the types of changes that may alter the outcome of a battle; and,

3. to assist the commander in determining which changes in an operation could be expected to return the significant improvement in a MOP.

Four conditions support the effective use of this process:

1. the using unit must have access to and be familiar with the Janus(A) combat simulation;

2. the unit must have an understanding of the differences between the Janus(A) simulation and the force-on-force simulation conducted at the NTC (see TRAC Technical Report, TRAC-RDM-TR-191);

3. an effective and timely qualification process must be established that allows a unit to conduct Janus(A) training soon after an NTC rotation; and,

4. the using unit must have an understanding of the variability of Janus(A) output.

The plan has seven steps. Figure 23 depicts these steps.

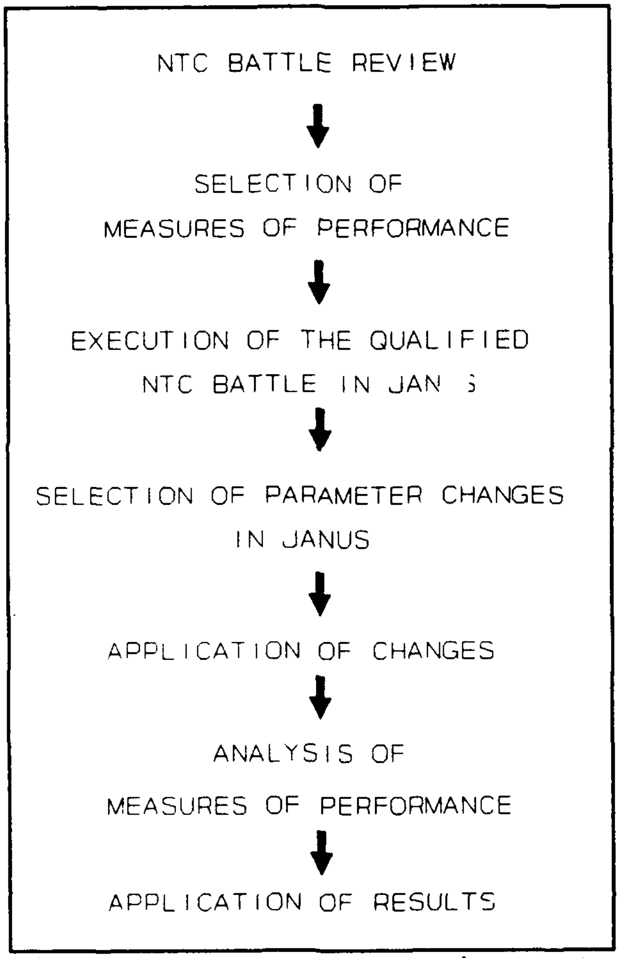

Figure 23 Seven Steps in Post-NTC Training With Janus(A)

C. THE SEVEN-STEP PROCESS FOR TRAINING WITH JANUS(A)

1. Step I. NTC Battle Review

During Step I the commander and his staff review the mission and critical events of the NTC battle. This review is based upon the NTC Take Home Packages (THP) and the records kept by the unit. The outcome of this step should be an understanding of the battle with respect to,

1. whether or not the mission was accomplished;
2. the time and location of critical events that helped determine battle outcome; and,
3. the identification of mission related goals.

In determining if the mission was accomplished, the unit should consider the goals specified in the mission statement and the commander's concept of the operation. Particular attention should be given to goals that are in the form of,

1. holding terrain;
2. seizing terrain;
3. destroying the OPFOR;
4. preserving the BLUEFOR; and,
5. maintaining contact with the OPFOR.

Attention is directed to goals such as these since Janus(A) is suited to providing output related to attrition, location of forces and detection. The identified goals provide a basis for determining which events are critical. The critical events should be related to the achievement of the goals.

2. Step II. Selection of a Measure Of Performance (MOP)

The outcome of this step is the selection of one or more Measures Of Performance (MOPs). These MOPs are related to the mission, goals and timing of critical events identified in Step I. Two characteristics are important in a MOP:

1. the MOP must be sensitive to changes made in the battle; and,

2. the MOP must possess a close relationship to the unit's goals.

A MOP that is based on attrition, engagement ranges or location of attrition should normally demonstrate sensitivity to changes in the battle. The following is an example of an attrition based MOP used in this thesis:

$$MOP = \frac{OPFOR\ LOSSES}{INITIAL\ OPFOR\ STRENGTH} + \frac{BLUEFOR\ SURVIVORS}{INITIAL\ BLUEFOR\ STRENGTH} .$$

3. Step III. Execution of the Qualified NTC Battle in Janus(A)

The qualified NTC battle should be executed in Janus(A) without modification. The execution of the qualified battle serves several purposes. The qualified battle serves as a second review the battle. If need be, the critical events identified in Step I may be revised.

This qualified battle serves as a reference point for the commander. The qualified battle results are compared to those results attained at the NTC. This comparison can give the

commander insiqhts into whether the results of the battle are do to "task" performance or a combination of planning and task performance [Ref. 12]. Here the term "task" has a broad range of meanings. For example, task may refer to conducting a successful counter attack by the reserves or destroying 60% of the enemy in a specific engagement area. Consider the following example. A unit obtains results in a qualified scenario that are superior to those obtained under the same conditions at the NTC. This may indicate that the commander's plan (as executed at the NTC and in Janus) is sound but the performance of one or more important tasks at the NTC was poor. This poor task performance may later be attributed to conditions present at the NTC such as gunnery skills at levels below those portrayed in Janus.

The qualified battle should be executed several times, so that variability in MOP values can be assessed. Once the commander is satisfied with his understanding of the qualified battle he is prepared for Step IV.

4. Step IV. Selection of Changes to Parameters in Janus(A)

The changes made to the qualified battle should be made with respect to,

1. the BLUEFOR mission;

2. the types of changes that were possible at the time of the battle given available time and resources;

3. the types of changes that might not have been possible at the time of the NTC battle but provide insight into those resources that may have improved the battle outcome had they been available (e.g., greater engineer support, more artillery, additional ground forces): and,

4. the types of changes that can be executed in Janus(A).

5. Step V. Application of The Changes

The changes to the qualified scenario should be applied in a manner that allows attributing changes in the MOP means to each selected change in the battle. One method of applying changes to the battle is to apply each change separately and to hold other conditions as they were in the qualified battle. This "marginal design" does not take into account possible interactions between parameters. As discussed in this thesis interactions can be significant, and the potential for interactions should be considered during this process. Whatever method is used, particular attention should be given to the variability in Janus(A). Again, several Janus(A) runs should be conducted for each scenario that has been altered.

6. Step VI. Analysis of the Measure Of Performance (MOP) Values

Comparisons of MOP values are affected by,

1. the inherent variability in battle outcome; and,

2. the possible variability introduced by operator interactions during the execution of a Janus(A) scenario.

The using unit should be aware of the inherent variability in Janus(A) outputs even with constant inputs. The variability

introduced by operator interaction should be minimized whenever possible. Minimizing operator interaction reduces the variability in MOP values that may be attributed to the operator attempting to replicate the same actions repeatedly. When possible, the changes should be applied so that the Janus(A) scenario can be executed without any operator interaction. If operator interaction is required, then the events that require initiation should be scripted. This scripting of events will help minimize the variability that may occur in the timing of operator controlled events.

7. **Step VII. Application of the Janus(A) Training Results**

Janus(A) training results can be applied in at least two areas. One area is in future planning and training. The Janus(A) results may indicate certain maneuvers or employment of systems that could increase a unit's ability to accomplish similar missions. If a tactical maneuver appeared constructive in the Janus(A) simulation, the commander might consider attempting a similar maneuver during subsequent training. If the commander has applied variations of a tactical plan in Janus(A), the simulation may provide indications of which variations seem the most promising for accomplishing the mission.

A second area is identifying resources that may aid in a unit's ability to accomplish missions similar to that in the qualified scenario. For example, changes in engineer support

seen as useful in Janus(A) could suggest what levels of additional assets could lead to improvements in battle outcome.

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8.	Defense Technical Information Center ATTN: DTIC, TCA Cameron Station Alexandria, VA 22304-6145	2

9. U.S. Army Library 1
Army Study Documentation and Information Retrieval System
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